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STUDIES AND RESEARCH CONCERNING BNFP

SPENT FUEL DISASSEMBLY AND CANNING PROGRAMS AT THE BARNWELL NUCLEAR FUEL PLANT (BNFP)

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ABSTRACT

Methods of disassembling and canning spent fuel to allow more efficient storage are being investigated at the BNFP. Studies and development programs are aimed at dry disassembly of fuel to allow storage and shipment of fuel pins rather than complete fuel assemblies. Results indicate that doubling existing storage capacity or tripling the carrying capacity of existing transportation equipment is achievable. Disassembly could be performed in the BNFP hot cells at rates of about 12 to 15 assemblies per day.

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1.0 INTRODUCTION AND SUMMARY

1.1 Purpose

Methods of disassembling and canning spent fuel to allow more efficient storage are being investigated at the BNFP. Studies and development programs are aimed at hot cell disassembly of spent fuel assemblies to allow storage and shipment of fuel pins only rather than complete fuel assemblies. The objective is to double the capacity for storage or triple the capacity for transportation of spent fuel as well as to stabilize the fuel for storage. The work has been supported by the U. S. Department of Energy, Fuel Cycle Projects Office, under Contract No. DE-AC09-78ET-35900.

The use of the BNFP mechanical headend spaces for the disassembly and canning of spent fuel has several advantages as compared to "in-pool" disassembly:

- Eliminates possible contamination of storage pool water
- Enhances visibility via shielding windows
- Reduces considerably operator radiological exposure and job fatigue
- Increases operational control and flexibility
- Eliminates interference with fuel receipt/storage operations in pools.

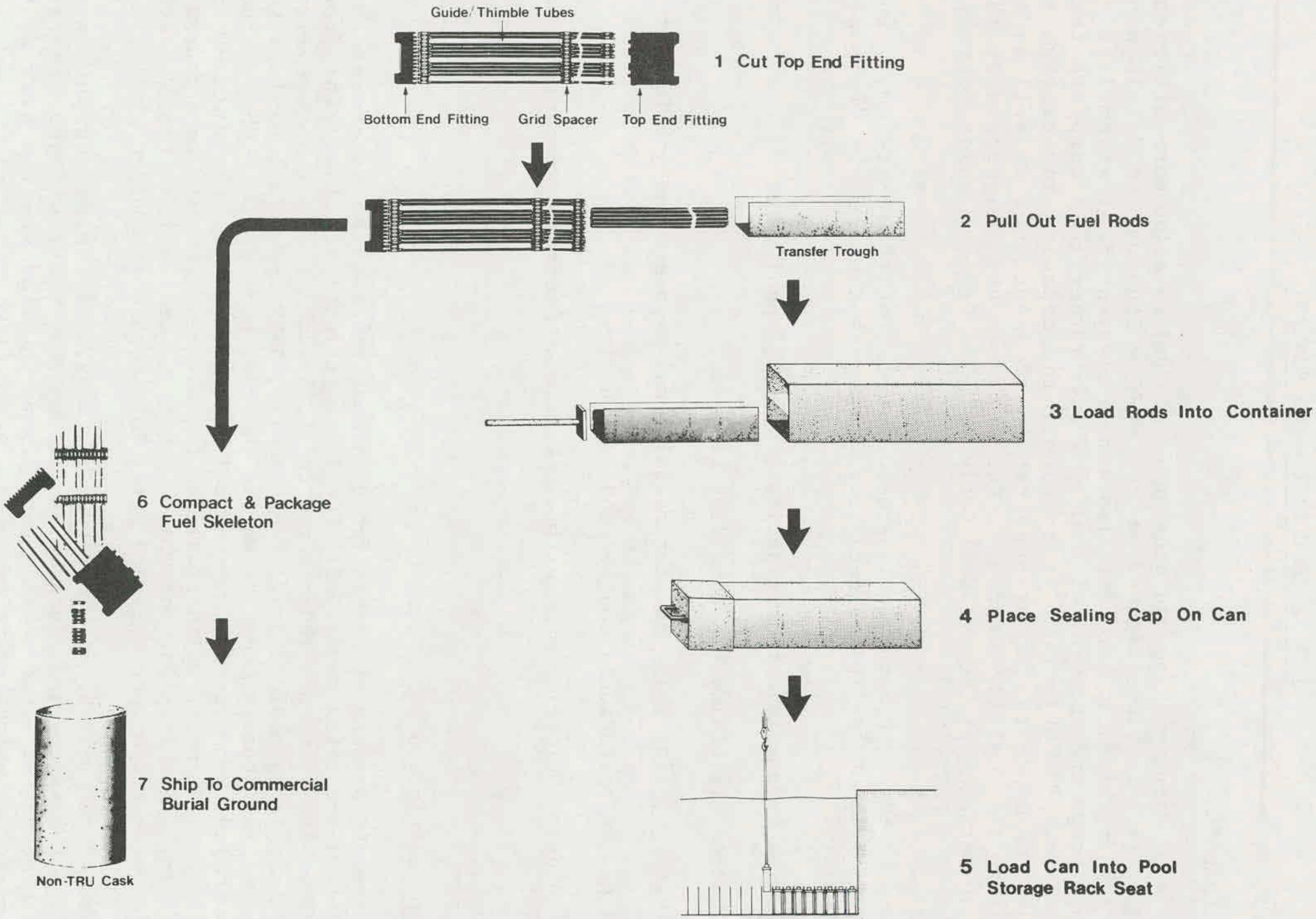
1.2 Scope

System Description

Two separate canning processes for reference pressurized water reactor (PWR) fuel are being developed. The first option loads fuel pins from two assemblies into a 23.50-centimeter (9.25-inch) square can that fits into a single assembly storage location in a BNFP spent fuel pool rack, thus doubling storage capacity within the same pool space. The second option loads pins from three assemblies into a 32.40-centimeter (12.75-inch) diameter cylindrical can for shipment off-site to a federal repository, thus tripling the capacity of a legal weight truck cask. Similar percentage increases are possible with BWR assemblies.

Studies of the nuclear criticality, shielding, and thermal output have verified the safety and adequacy of this concept for fuel aged greater than three years. Storage rack seismic and loading studies have also been performed which verify technical feasibility.

Figure 1-1 schematically shows the first option by which fuel pins from two assemblies are canned and returned to the pool storage rack.



FUEL DISASSEMBLY FLOW PROCESS (OPTION 1)

FIGURE 1-1

Figure 1-2 shows the second option by which fuel pins from three assemblies are canned and loaded into a truck cask.

The BNFP mechanical headend spaces shown on Figure 1-3 provide the dry, remotely operated and maintained facilities in which the disassembly and canning equipment would be installed. The facilities are shown with all reprocessing equipment removed. The facilities as shown in the figure are connected to the existing storage and transferring pools of the BNFP. Under either option, the disassembly, canning, and waste volume reduction processes would be implemented in the remote cell. The waste packaging and any dry fuel receipt or dry outloading of canned fuel pins would be accomplished in the remote support cell.

The fuel assembly would be transferred from the pool to the remote cell. In the remote cell, the following operations would be performed:

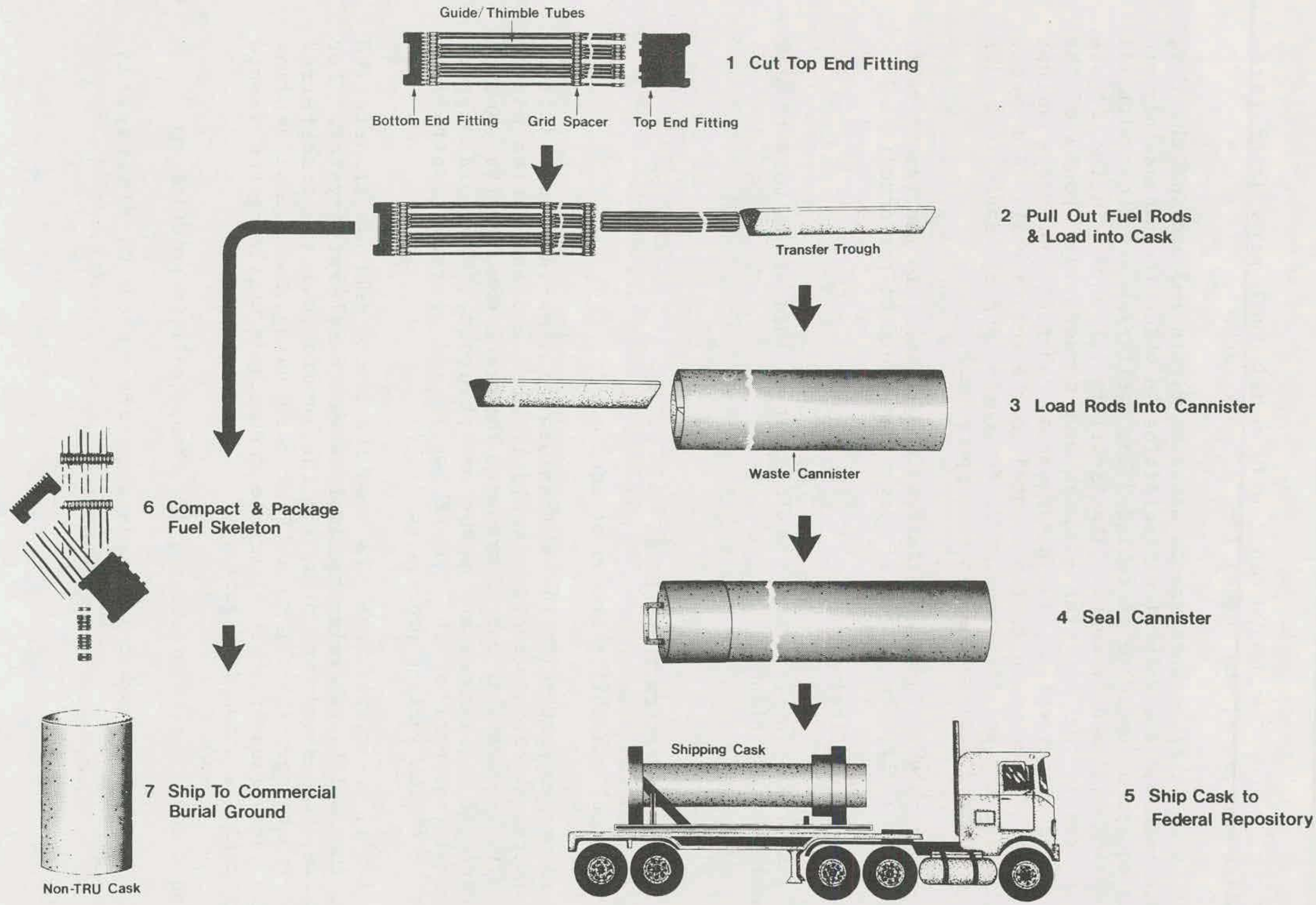
- Remove top end fitting
- Pull out fuel pins (an option would exist at this stage to vent and reseal fuel pin plenums)
- Load pins into can
- Seal can and perform inspections
- Compact fuel assembly skeleton structure.

In the remote support cell, the nontransuranic (non-TRU) end fittings and compacted skeleton structure would be packaged and outloaded for shipment to a commercial burial ground. The crane room permits contact maintenance of the cranes and power manipulators. The cold support areas permit shipment of the non-TRU waste and operator control and monitoring of the various processes.

For Option 1, the canned fuel pins from the remote cell are transferred back to the pool by reversing the fuel assembly delivery system. For Option Two, the canned fuel pins from the remote cell are transferred via the remote support cell to a truck cask using a dry cask loading method. Variations of these alternate dry methods utilizing the remote support cell are shown in Figure 1-4.

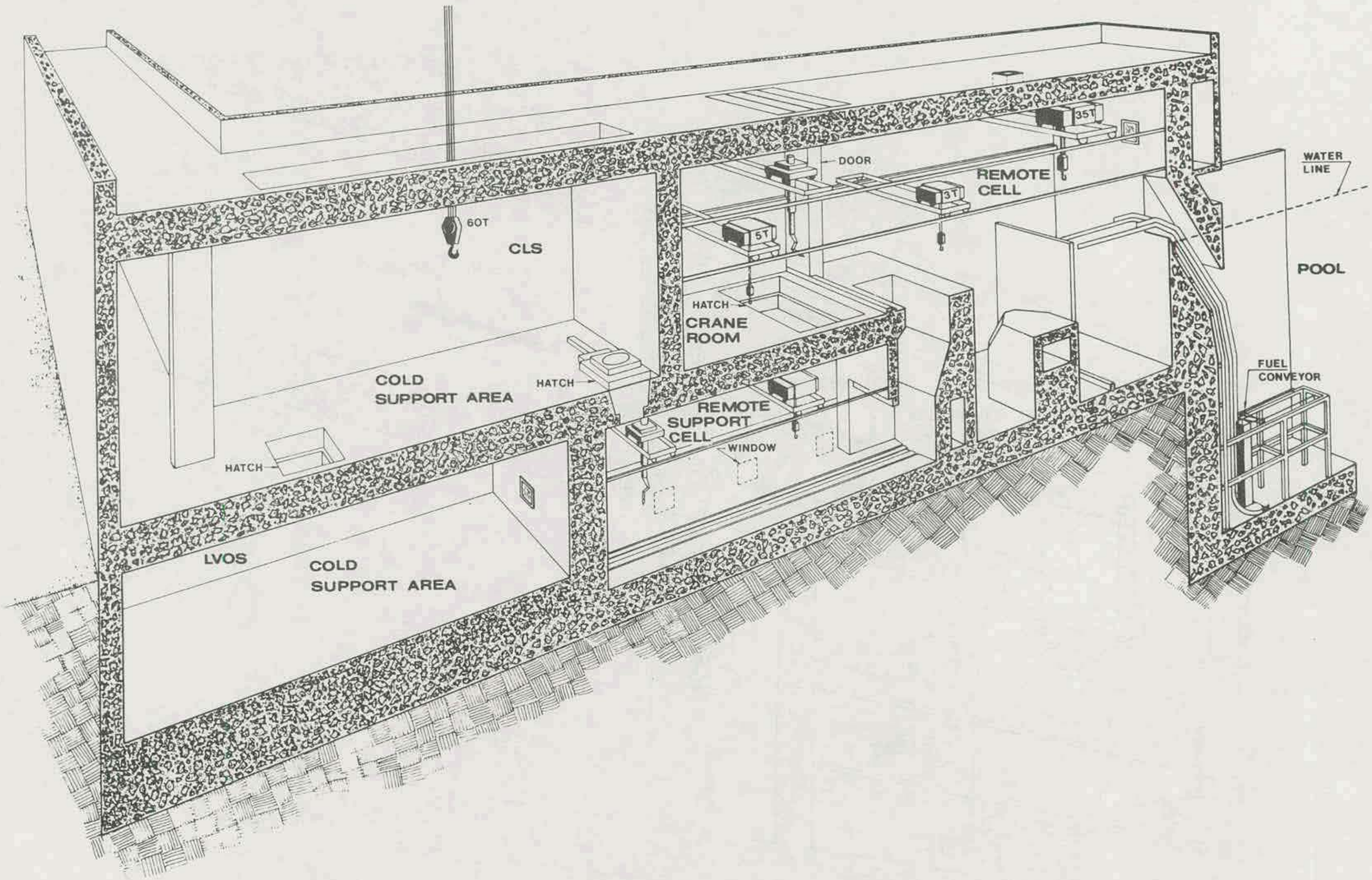
To support these remote processes, the remote cell is provided with:

- A demonstrated fuel delivery system from pool to disassembly equipment
- Three (3) cranes
- A power manipulator
- Five (5) wall shielding windows (in a disassembly mode)



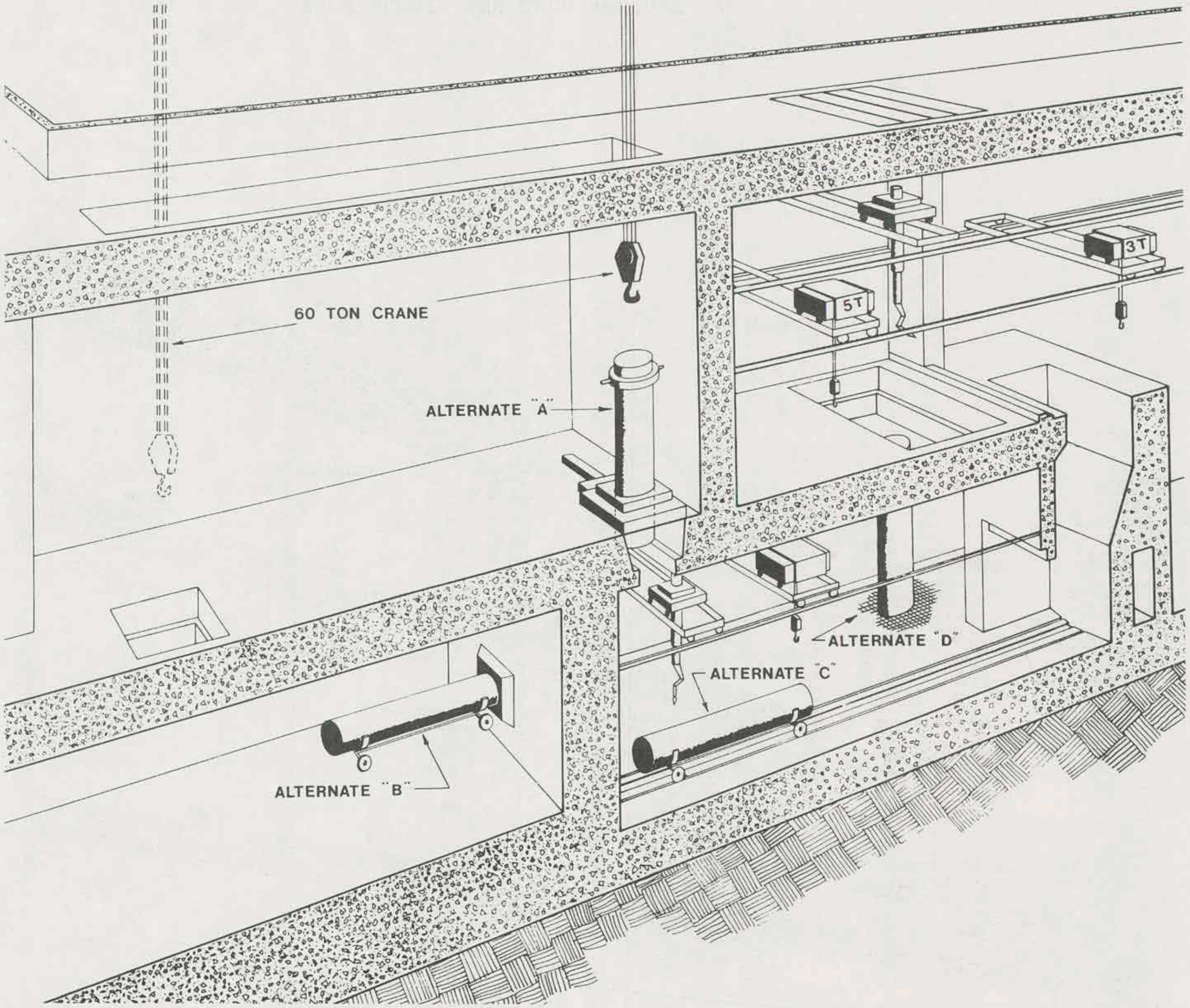
FUEL DISASSEMBLY FLOW PROCESS (OPTION 2)

FIGURE 1-2



BNFP REMOTE AND COLD SUPPORT AREAS

FIGURE 1-3



ALTERNATE DRY UNLOADING POSITIONS

FIGURE 1-4

- One (1) ceiling shielding window
- Master-slave manipulator capability at each wall window
- Multiple periscope capability on two walls
- Various utility services at each wall window (i.e., steam, air, water, decontamination solution and electrical power)
- Multiposition remote television capability
- Multiple undedicated pipe and removable service plug penetrations on two walls.

Figure 1-5 is a photograph of the remote cell (with reprocessing equipment installed) that shows much of the remote support equipment installed.

The remote support cell is provided with:

- A demonstrated non-TRU waste transfer, packaging, and outloading system
- A crane
- A power manipulator
- Four (4) wall shielding windows
- Same as the last five items above provided for the remote cell.

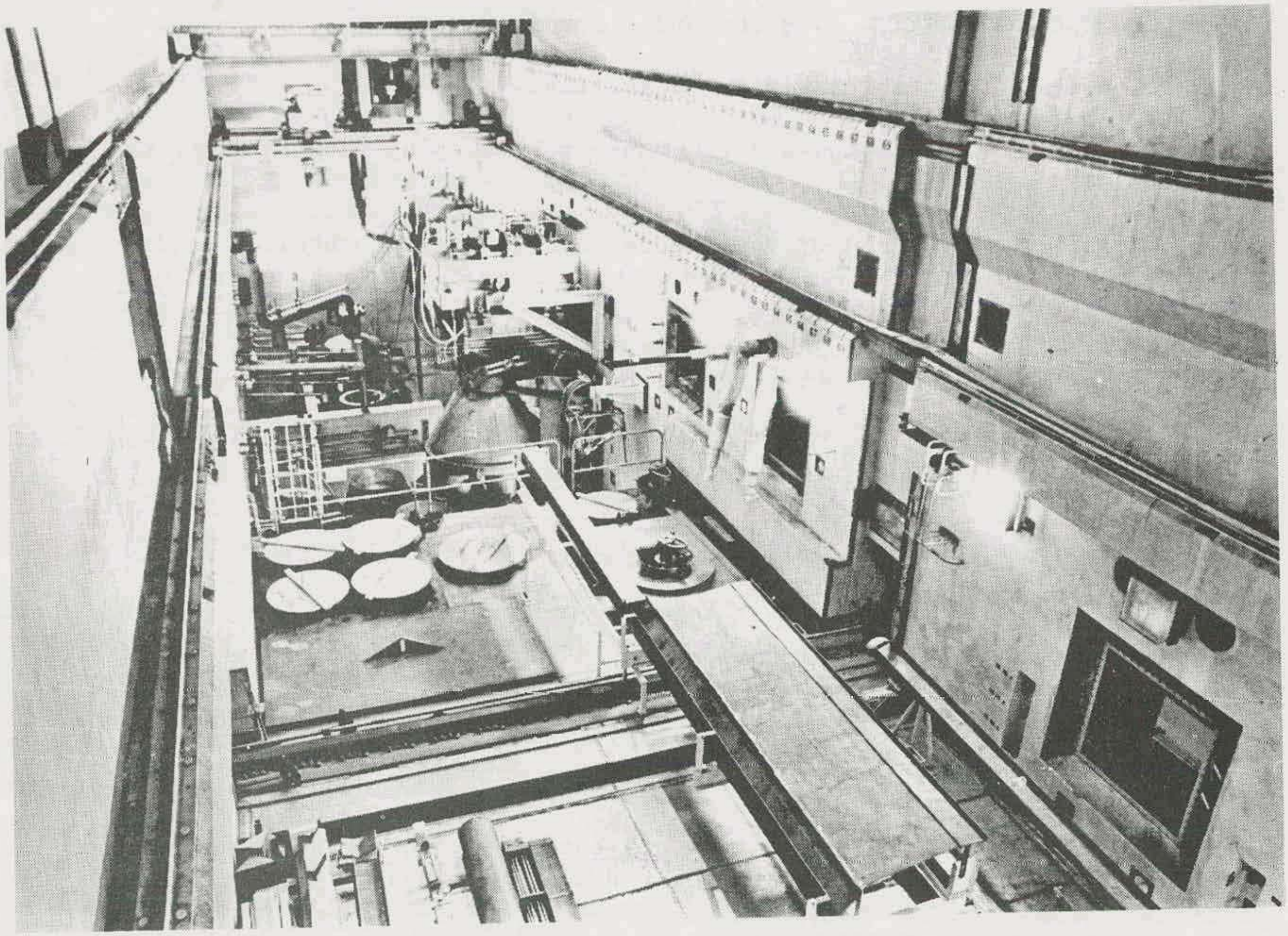
Component Development

As a first step in hardware development, specific remote disassembly and canning steps were isolated that required design criteria definition. These included:

- End fitting removal methods
- "Fuel pin-from-skeleton" removal methods
- "Fuel pin-to-can" loading methods.

Other steps either involved existing remote equipment or rather straight forward remote material handling devices and have not been demonstrated. The intent of these development efforts was to demonstrate feasibility and narrow the range of design parameters.

End fitting removal methods were investigated to cut the top end fitting from the fuel assembly. The desired cutting plane is between the end fitting and the top of the fuel pin bundle. In this region, only control rod thimble tubes (and in some cases, sheet metal shrouds) are found in the assembly cross section. Demonstration effort focused on sawing and laser cutting, as a result of an initial literature review of various candidate mechanical and thermal cutting methods.



BNFP REMOTE CELL

FIGURE 1-5

As an additional option during pin pulling, if the fuel pin requires depressurization prior to repository emplacement, a low-power laser system was investigated to vent and reseal the individual pin plenums which would require a minimum of in-cell equipment.

Two aspects of "fuel pin-from-skeleton" removal methods required investigation. These were how to engage the fuel pin and with how much force to pull. Various design parameters of a "puller-to-fuel pin" engagement device or "biter" required definition.

Questions concerning the configuration of the "biter" tooth (i.e., its rake and relief angles), necessary hardness, and biting force to grab the pin end plug for pulling had to be answered. Included were the forces required to pull fuel pins from various fuel assembly skeletons. The fuel pin is retained in the skeleton by the spacer grid via friction to allow for growth in the reactor. It is these friction forces that must be overcome by the pulling force.

Once the fuel pins are pulled from the skeleton, they must be collected and loaded into a can. In an effort to minimize powered systems requiring remote maintenance, a gravity feed collection system was selected consisting of a sloping surface terminated by a collection trough. First, the slope of the surface was established to ensure reasonably level pin stacking in the trough. Also, selected trough cross sections were tested to see which reduced the pin loading forces to reasonable levels. These forces develop during the axial push of the free pin bundle into the can. Also, the range of these loading forces needed definition to fix the design of the can loading drive. As an associated study, testing was done to develop a relationship between the loading force required for a given collection of fuel pins versus the cross-sectional area of the can section being loaded.

System Development

The system development for disassembly and canning processes consisted of both hardware demonstrations and integrated concept layouts and designs.

One hardware demonstration consisted of defining the problems associated with transfer of an intact dummy fuel assembly through the remote cells. Another considered the integration of as many steps as feasible in a disassembly and canning process to provide an initial refinement of estimated throughput capacities.

A fuel assembly transfer system to convey fuel from the storage pool to the remote cell already exists. It is usable "as is" in a disassembly/canning process. Using our present knowledge of existing equipment and estimating processing times for components not yet manufactured, an initial estimate in throughput time was developed.

To ensure that adequate space and viewing requirements could be met, initial equipment layouts for both the disassembly and canning options were made. Initial design concepts to support these layouts were established to define the spatial envelopes of the individual equipment items that would consitute the integrated system.

1.3 Summary of Results

Results indicate that the BNFP mechanical headend can disassemble spent fuel assemblies and repackage the fuel pins in a dry, remotely operated and maintained facility. Testing of individual disassembly operations have verified our belief that the process can be readily performed in the BNFP mechanical headend spaces. Using dedicated equipment (i.e., no remote crane or manipulator used for in-line processing) rates of about 12 to 15 assemblies per day (approximately 6 MTU) are projected. This process rate is believed to be 3 to 4 times greater than a similar process in a contaminated pool.

The essence of the disassembly/canning process development is shown by photograph in Figure 1-6. All fuel pins from two prototypic fuel assemblies are shown loaded into a can. The upper right half section contains the pins from a dummy Westinghouse 17 x 17 fuel assembly; the other half section, the pins from a dummy Babcock and Wilcox 15 x 15 fuel assembly. The can was loaded using component development equipment and subsequently demonstrated to fit within a mock-up section of a typical PWR rack. This demonstrated doubling of pool storage capacity by putting the fuel pins from two PWR assemblies into a rack section that would normally hold only one PWR fuel assembly.

Table 1-1 summarizes the component development effort for the reference PWR fuel.

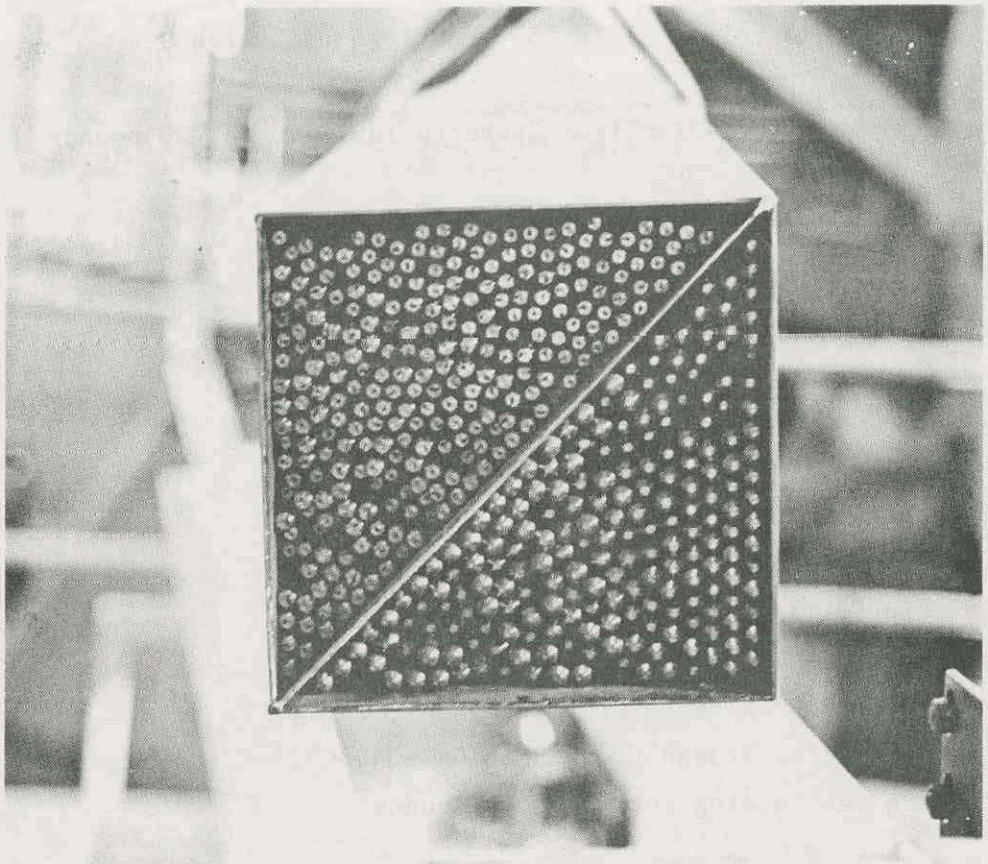
Three prototypic PWR fuel assemblies were available for the development effort. All assemblies were used to establish force ranges required to pull fuel pins from the spacer grids. The pins from the Westinghouse 17 x 17 assembly were used for biter tooth development as a "worst case" challenge (i.e., smallest diameter and smooth side walls of the fuel pin end plug). The pins from both the Westinghouse 17 x 17 and the Babcock and Wilcox 15 x 15 assemblies were used to select the pin collector slope and to establish limits on the forces required to load the free pin bundles into both square and round can sections.

Development work at the BNFP has verified the following data:

(1) The square and cylindrical cans can be loaded without damaging or placing excessive axial load on the pins.

(2) Proof-of-principle demonstrations for laser and friction saw removals of end fittings and laser drilling, depressurizing, and resealing of fuel pin plenum facsimiles have been successfully completed.

(3) Development of a biter tooth configuration for a device to pull the fuel pin free from the assembly spacer grids has been successful (i.e., hardness-60 Rockwell C [Rc], relief angle-10°, and rake angle-30°).



SQUARE CAN LOADED WITH FUEL PINS
FROM TWO COMPLETE PWR FUEL ASSEMBLY DUMMIES

FIGURE 1-6

TABLE 1-1

FUEL PIN REMOVAL AND LOADING RESULTS

- Dummy PWR Test Assembly Types
  - Westinghouse (17 x 17)
  - Babcock & Wilcox (15 x 15)
  - Gulf United Nuclear (15 x 15) (Westinghouse Reload)
- Force to Pull Fuel Pins from Spacer Grids - 20 to 200 pounds
- Fuel Pin Puller Parameter Development
  - "Optimal" Puller Biter Force - 70 pounds
  - Minimum "Expected" Pin Pull - 200 pounds
  - Maximum "Expected" Pin Pull - 350 pounds
  - Biter Tooth Hardness - 60 Rc.
  - Biter Tooth Relief Angle - 10°
  - Biter Tooth Rake Angle - 30°
- Fuel Pin Collector Slope to Trough - 8°
- Fuel Pin Can Loading Development (Pool Storage)
  - Pin Collector Trough Cross Section - 45°
  - Square Can Loading Force - 1300 pounds
- Fuel Pin Can Loading Development (Truck Cask)
  - Pin Collector Trough Cross Section - 120°
  - Round Can Loading Force - 1400 pounds

Individual pin pulling forces were demonstrated to range between 20 and 200 pounds. A "biter" with this tooth configuration, which grips the pin with a bite of 70 pounds will prevent slippage up to a pulling force of 200 pounds but will not develop pulling forces in excess of 350 pounds before slipping free.

(4) It was found that a collector slope of 8° tended to level the profile of the free pins in the collection troughs. Utilizing this slope, it was found that selected trough cross sections of 45° for square cans and 120° for round cans preshape loose pin bundles, so that pin loading forces do not exceed acceptable levels (less than 1500 pounds) and mechanical jams are minimized.

(5) Using both vertical and horizontal handling of the fuel assembly, transfer of an intact fuel assembly through the headend spaces was demonstrated.

(6) The system layout and design development has shown that adequate space and remote viewing does exist in the remote cell for the installation of a fuel disassembly/pin canning process for either option.

1.4 Summary of Conclusions

Doubling pool storage and tripling truck cask shipping capability appear feasible based on development work performed at the BNFP. This is accomplished by disassembly of the fuel assembly and canning of the fuel pins. The dry, remote disassembly and canning process in the headend cells, as compared to "in-pool" disassembly, offers the advantages of increased rates, elimination of disassembly contamination of pool water, enhanced visibility, reduction of operator dose and fatigue, increased flexibility, and unlinking of fuel receipt/storage/disassembly operations.

1.5 Summary of Recommendations

The program should be continued based on the advantages to either AFR's or long-term repositories and the demonstrated feasibility as indicated by this report.

The logical program steps would be, in order:

- Continue component design/development
- Fabricate prototype systems for cold demonstration
- Evaluate results, modify as required and redemonstrate
- Demonstrate under "hot" conditions modifying as required
- Parallel above steps with associated software package (i.e., procedures and licensing considerations).

2.0 CUTTING TECHNOLOGY DEVELOPMENT

2.1 Purpose

The purpose of this section is to describe the investigation and feasibility studies performed on two selected methods for cutting through a fixed array of thin-wall stainless steel tubes. The array of twenty thin-wall tubes simulates the basic configuration of the top end section immediately adjacent to the bottom of the top end fitting of a PWR-type fuel assembly. The cutting of the tubes removes the top end fitting as a first step in removal of the fuel assembly fuel pins to permit volume reduction during encapsulation.

The criteria in studying commercial cutting methods as a step in PWR spent fuel disassembly required production-orientated capacity, dry, horizontal processing in a hot cell and compatibility with other disassembly and encapsulation equipment concepts. Objectives of the initial feasibility study were to:

- Minimize fixture/tool force on, and vibration to, the spent fuel assembly during positioning and cutting operations
- Minimize complexity and cost of in-cell equipment
- Minimize swarf in-cell and heat loads in the fuel assembly
- Minimize remote operating and maintenance changes and costs
- Minimize critical alignment requirements and waver of tool and its resulting cut envelope to assure no cutting of the fuel rod cladding
- Minimize equipment and test sample requirements for cutting parameter verification in-cell
- Verify adaptability to a continuous production system.

The program was concerned with the:

- Mechanical process related to friction sawing
- Thermal process related to laser cutting.

Other cutting processes and methods for this application were not included because of prior investigation by others, impracticality, or cost for hot in-cell application.

2.2 Scope

2.2.1 Friction Sawing

Friction sawing was considered as a mechanical metal cutting process since it was designed specifically for commercial cutting of thin-wall/thin-gauge stainless steel on a continuous production basis.

Unlike conventional sawing, friction sawing utilizes heat to soften the metal in the cut path so that it can be easily removed. Friction sawing requires a tool with great length in respect to work thickness; therefore, a band saw machine is usually used for this purpose. The saw band travels at a very high velocity, usually about 3000 to 15,000 feet per minute, geared through a motor turning about 1800 revolutions per minute. Slight pressure of the metal workpiece against the saw band edge generates heat immediately in front of it. The heat is generated faster than the cut zone can dissipate it without substantial increases in its temperature. Near the red heat range, the tensile strength of the metal drops rapidly. At a point slightly above red heat, but below the melting point, the metal is swept away by the saw band teeth action. This exposes new material to the same heating action and the process is continued until the workpiece is severed.

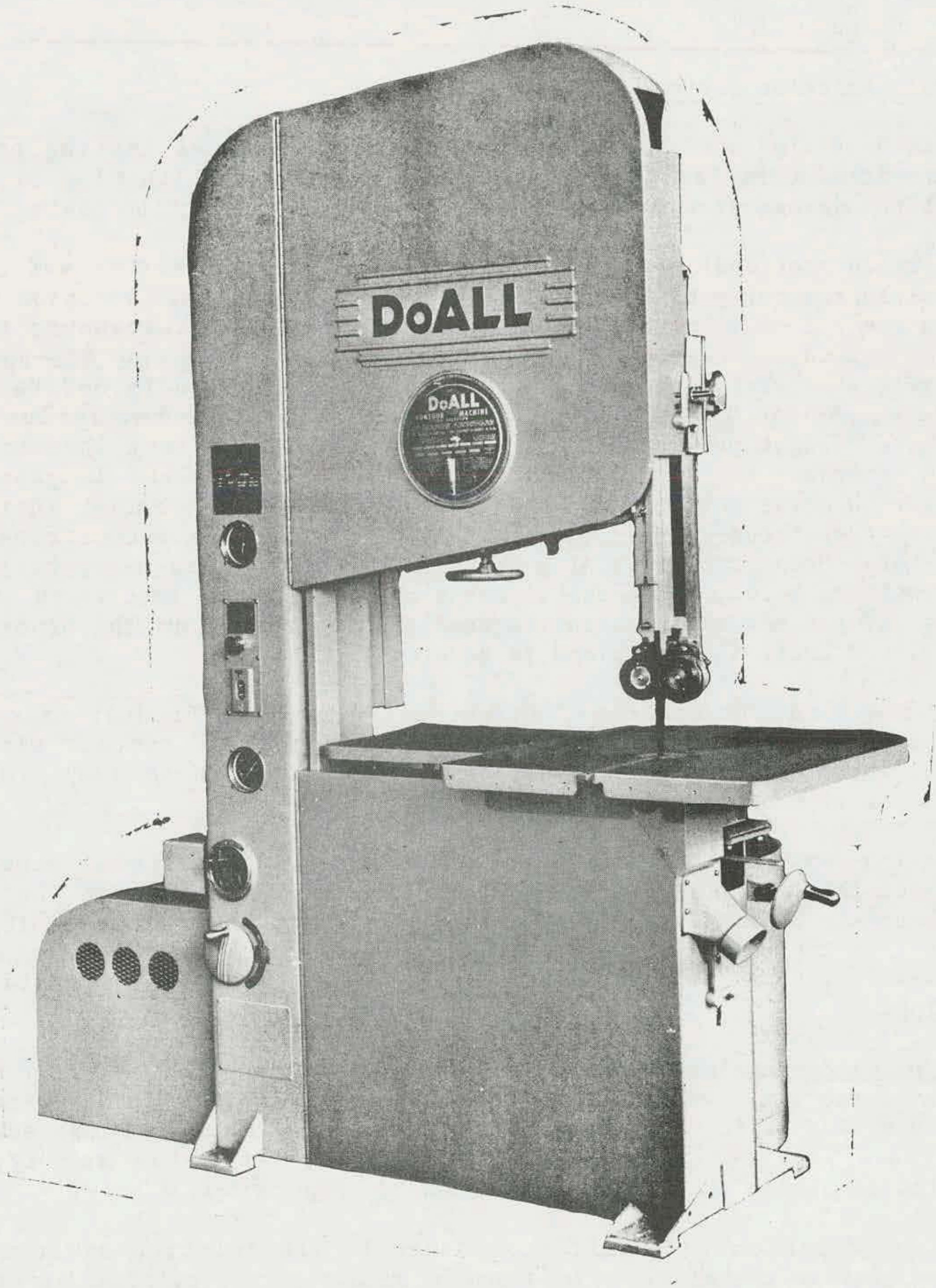
The saw band, in contrast, is not affected or softened, since the duration that any given area of the saw band is in contact with the metal workpiece is small in comparison to the time it is away from the work and is cooling.

Friction sawing is dependent upon the high unit pressures generated between the tips of the saw band teeth and the work to remove the metal weakened by heating. Therefore, thin metals that inhibit heat dissipation from the point of application such as the hollow, thin-wall, stainless-steel, guide tubes in PWR fuel assemblies are ideal for friction sawing.

A typical commercially-available friction sawing machine is one containing two large vertically mounted wheels, usually 36 inches diameter, capable of rotating at very high speeds which drive the endless saw band on their periphery. The machine basically resembles any typical vertical machine shop band saw as shown in Figure 2-1.

For the disassembly application in-cell, the friction saw could be redesigned to contain less mass and be remotely controlled and operated. Saw band changes and the in-cell maintenance could be redesigned for remote implementation. The drive motor and machine controls could be located outside of the hot radiation area simplifying the remote maintenance.

The feasibility of friction sawing for this application, although promising, will require further study beyond the results of the



TYPICAL MACHINE SHOP BAND SAW

FIGURE 2-1

short-range program recently completed. The short-range program concerned itself with determining the:

- Amount and size of the swarf and dust expelled during cutting together with a definition of equipment needs for the removal of swarf from the workpiece and the saw.
- Length of time required to cut the array of thin-wall tubes, the range of cut characteristics and the relationship between cut characteristics at different points in the array
- Assurance that the cutting operation would not breach the fuel pin cladding.

A longer-range program should consider such factors as noted below:

- Saw band life which is a function of fatigue, which in turn is a function of the saw speed and the length of the saw band
- Feasibility of remote operation, control and saw band replacement
- Redesign of a commercial friction saw for application in the radiation environment of a hot-cell.

2.2.2 Laser Cutting

The word "laser" is an acronym of the words, "Light Amplification by Stimulated Emission of Radiation". A laser is a highly coherent beam of light capable of being focused to a diameter less than that of a human hair generating extremely high power densities at the point of focus. Metal cutting lasers are normally continuous beam, CO_2 lasers. At the impingement point of the beam on the workpiece, a void or hole is melted from which the melted metal is immediately blown by a jet of air or inert gas. If the metal were not blown away, it would quickly resolidify after beam removal. Since the heat input to the workpiece is extremely localized in comparison to other thermal cutting methods, the size of the heat-affected zone and thermal damage to adjacent surfaces or components are minimized.

Focusing the beam onto the workpiece is accomplished by an optical system which can also shape the beam cross section. A relatively simple change in optics can provide the finely focused beam for drilling, cutting, or welding, or a broad area beam for surface heat treatment or metallizing. An important aspect of the laser beam is the fact that it is directed to the workpiece solely via an optical system. Therefore, the laser beam as a tool has no wear.

A typical industrial laser generally has six subsystems integrated into a total system. The subsystems consist of optics, their support structure, inert gas flow, power supply, water or gas cooling and operating control systems. For the proposed application of cutting thin-wall thimble tubes of a spent PWR-type fuel assembly, only the optics, their support structure, and a jet nozzle for directing inert gas flow to the cutting area would be located in the hot cell.

2.3 Results

2.3.1 Friction Sawing Short-Range Test Program

During the program, various cutting arrangements were utilized and a range of operating parameters were investigated to establish cutting feed rate, saw band speed and pitch, and spacing limitations between the vertical plates of the tube holding fixture as shown in Figure 2-2.

In the friction sawing study, the lack of burrs on one side of the tube face to that of the opposite side of the tube face should be investigated further so that any possible burr interference to the fuel pin pulling equipment can be avoided.

Proof of principle was demonstrated for friction sawing in this application as shown in Figure 2-3. However, the trend toward more desirable cutting characteristics (i.e., coarser swarf, reduced dispersion of swarf, and reduced burr buildup) at lower speeds warrants further study at speeds below the friction sawing range. This would allow consideration of saws whose space envelopes could be more compatible with the other dissassembly equipment.

Further details of the test program are described in Appendix A.

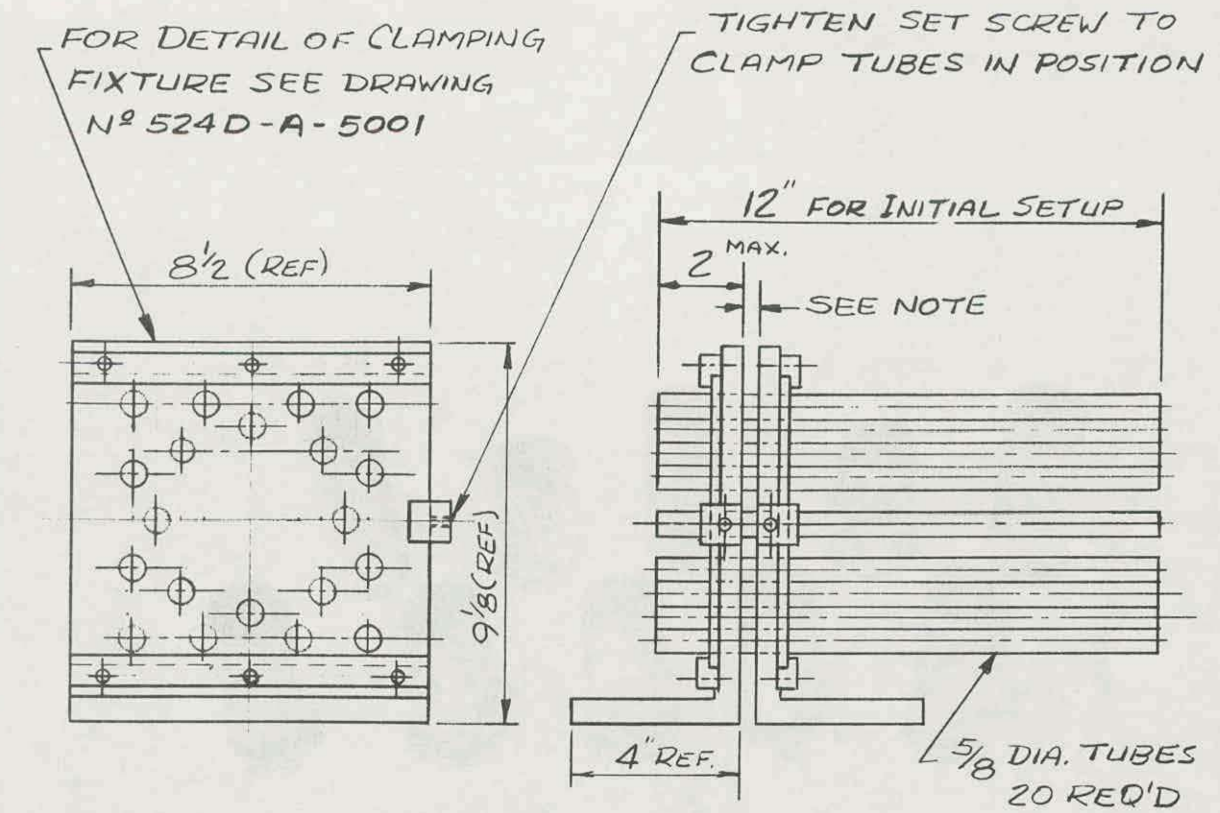
2.3.2 Laser Cutting Feasibility Tests

An initial feasibility study was performed by Avco-Everett Metalworking Lasers Development Laboratory to determine the ability of a 15-kilowatt, continuous wave (CW), CO_2 laser to cut an array of stainless-steel tubes held in a geometric arrangement simulating the thimble tubes of a PWR-fuel assembly.

Prior to this test, most development and commercial efforts toward laser cutting had been directed toward shape cutting or excess material removal operations in simple geometries where the workpiece is nearly flat and can be easily positioned within the focal plane of the laser beam.

During this program, various cutting arrangements were utilized and a range of operating parameters were investigated to establish cutting rate, laser power requirements, gas jet nozzle positioning, and spacing limitations for the vertical tube support/positioning plates of the tube holding fixture shown in Figure 2-2.

In the laser cutting study, the preferred position for the gas jet nozzle appeared to be as close as possible to the tube surface. The size of the gas nozzle used in the tests prevented its being placed in its preferred position. Also, the gas nozzle was observed to overheat



NOTE:

TO BE DETERMINED BY MINIMUM SPACING BETWEEN PARTICULAR FUEL ASSEMBLY BOTTOM SURFACE OF TOP END FITTING AND TOP SURFACE OF FUEL ASSEMBLY TOP END PLUGS.

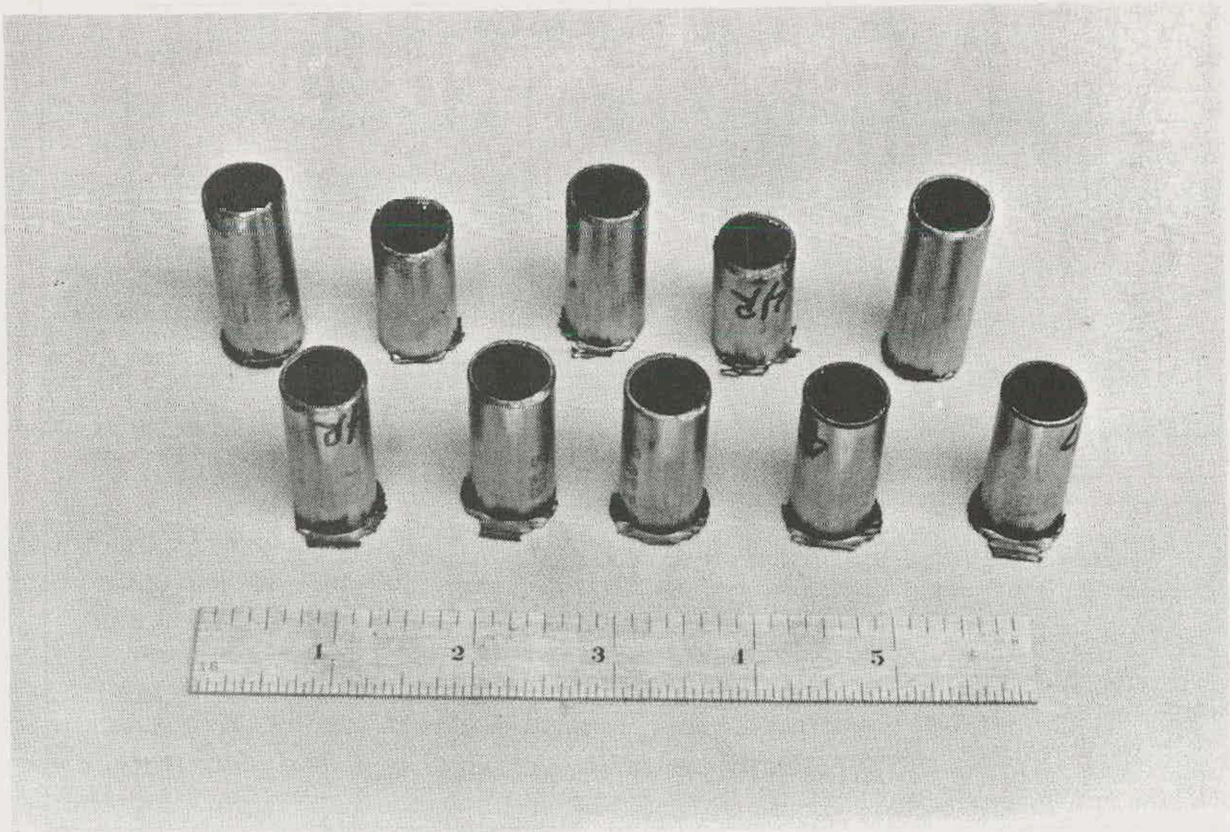
QUAN.	MATERIAL DESCRIPTION	QUAN.	MATERIAL DESCRIPTION

△	DATE		DR.	CHK.	DES.	ENG.	APPR.	APPR.

AECNS		JOB NO.	DRAWING NO.	REV.
		DEP-		

ARRANGEMENT FOR EXPERIMENTAL CUTTING OF DUMMY TUBES

FIGURE 2-2



TYPICAL CUT SURFACES

FIGURE 2-3

during the 1.4 minutes required for a single pass across the tube array. This indicates that the existing nozzle must be redesigned with improved cooling for the required duty cycle. Thermal expansion caused by the overheating restricts the gas flow path and shadows a portion of the laser beam.

In spite of these limitations, proof of principle was demonstrated for laser cutting in this application. However, further refinements in observed cut quality would be required prior to inclusion of this cutting method in a disassembly operation.

Further details of the test program are described in Appendix B.

2.4 Conclusions and Recommendations

The investigation of friction sawing and laser cutting has demonstrated two effective methods for cutting stainless-steel tubes arranged in a geometry simulating the thimble tubes of a PWR-type fuel assembly. Tubing segments which have been cut using the friction saw generally exhibit even cuts with minimum external burr buildup while those cut with the high-power laser generally exhibit even kerf, without the tendency for the tubing ends to close off.

Additional cutting tests are recommended. Promising results into the preliminary investigations into friction sawing and laser beam cutting of thin-walled, stainless-steel tubes have been achieved. In the case of laser cutting, this was achieved using optics and gas-jet nozzle hardware designed for cutting solid cross sections, not tube arrays. For both methods, additional effort is required to optimize the cutting techniques in order to improve their effectiveness, particularly in the case of laser cutting. Development of a gas nozzle designed for use in cutting the fuel assembly thimble tube configuration is recommended. Improved cooling and directional control of the gas flow would be design objectives. The effectiveness of inert gases other than helium or mixtures thereof should also be studied to determine whether equal or improved cutting quality and rates can be realized. Replacement of helium could lower gas cost.

As an alternative to moving the workpiece in a linear motion into the laser beam, rotation of the workpiece beneath the beam impingement point should be studied.

Swarf levels generated during friction sawing and smoke and fume levels generated during the laser cutting process also require evaluation.

3.0 PULLER-TO-FUEL-PIN ENGAGEMENT (BITER) DEVELOPMENT

3.1 Purpose

The pins from the Westinghouse 17 x 17 dummy were used in the fuel pin puller parameter development. These zircaloy-clad pins have the smallest diameter and are terminated by smooth end plug surfaces at one termination. The small diameter and absence of indentations or ridges offered the greatest challenge to development of the biter tooth. This required the biter tooth to create its own indentation in the small area of the solid cross-sectional end plug. The indentation had to be sufficient to resist the shear forces that develop during the axial pulls of up to 200 pounds required to remove "worst case" pins from the spacer grids.

So as not to overstress pins, it was also desired that the biter pull free at, or before, an upper limit of 350 pounds. This is less than one- third of the cladding yield strength and, therefore, would prevent overstress of the cladding. This is a backup to overload sensing which would be designed into a biter assembly and release the biter force at overload indications.

The spatial envelope that a biter mechanism must conform to and operate within impacts its design. The cross sections of its structural members are fractions of this envelope. Consequently, the smaller the envelope, the smaller the cross sections and the smaller are the forces that can be developed to bite the fuel pin.

Design criteria of:

(1) A processing rate of 12 to 15 assemblies a day,

(2) A pin pulling rate of 1 inch per second, and

(3) A pin pulling rate of 12 to 15 assemblies per 8 hours required pulling one fuel pin row during a given pull.

The biter envelope is, therefore, that area whose width is equal to the fuel pin pitch and whose height is the distance between the pins in the row above and the pins in the row below the row being pulled.

This area is smallest among PWR's in the Westinghouse 17 x 17 assembly justifying development with it.

Configuration parameters of relief angle, rake angle, and width of biter tooth were varied to reduce biting force required.

It was, therefore, necessary to design a biter that could indent the smooth cladding so as to:

- Hold a minimum pull (i.e., 200 pounds)

- Release before an upper limit (i.e., 350 pounds)
- Minimize biting force required (i.e., 50 to 100 pounds)
- Dimensionally not exceed the defined envelope.

3.2 Results

A schematic of the biter testing setup is shown in Figure 3-1.

Using this setup, three designs of the biter tooth pairs were used. Each design was fabricated in three hardnesses (i.e., Rc 20, 40, 60) for a total of nine testing pairs.

Design	Rake X (Degrees)	Relief X (Degrees)	Tooth Width (Fraction of Pin Diameter)
A	15°	5°	1/3
B	15°	5°	2/3
C	30°	10°	1/3

Figure 3-2 shows the results of this testing. Note that Design "C" at a hardness of 60 Rc gave the best performance (i.e., force exceeds 200 pounds at the lowest biter force).

Using this biter pair, repetitive testing was then performed to determine statistically what biter force would ensure results in the "pull-to-200 pounds-release-at-350 pounds" range discussed in Section 3.1.

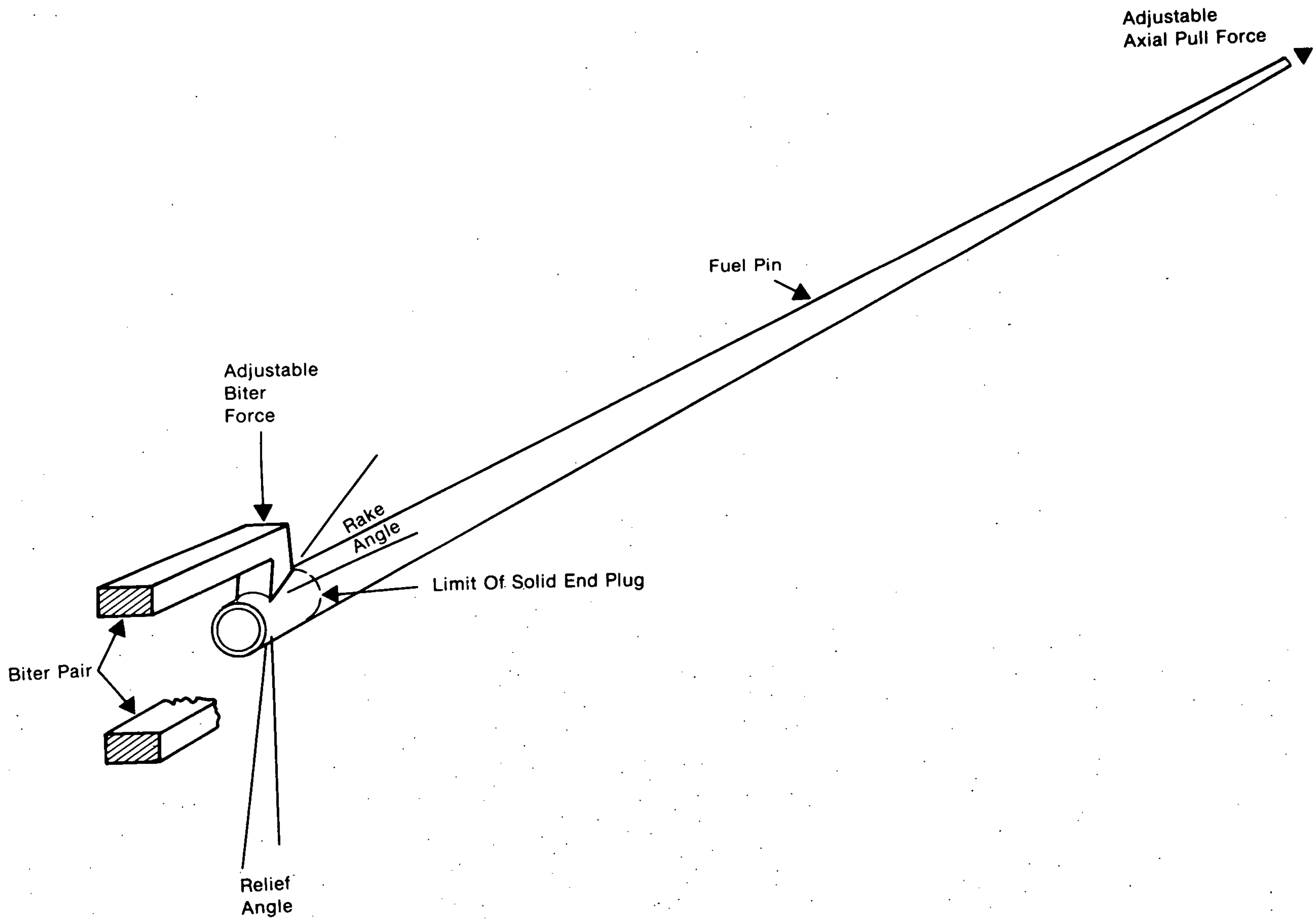
These results are shown in Figure 3-3. Note that 70 pounds of biter force established a tolerance limit in which 99% of all pulling forces will fall essentially in the 200- to 350-pound range with a confidence of 99%.

Note, also, that the mean at this biter force was 272 pounds which times 17 pins per row is less than 5000 pounds. This establishes a design criteria for the bed that pulls the row of pins from the assembly at 5000 pounds axial load.

3.3 Conclusions and Recommendations

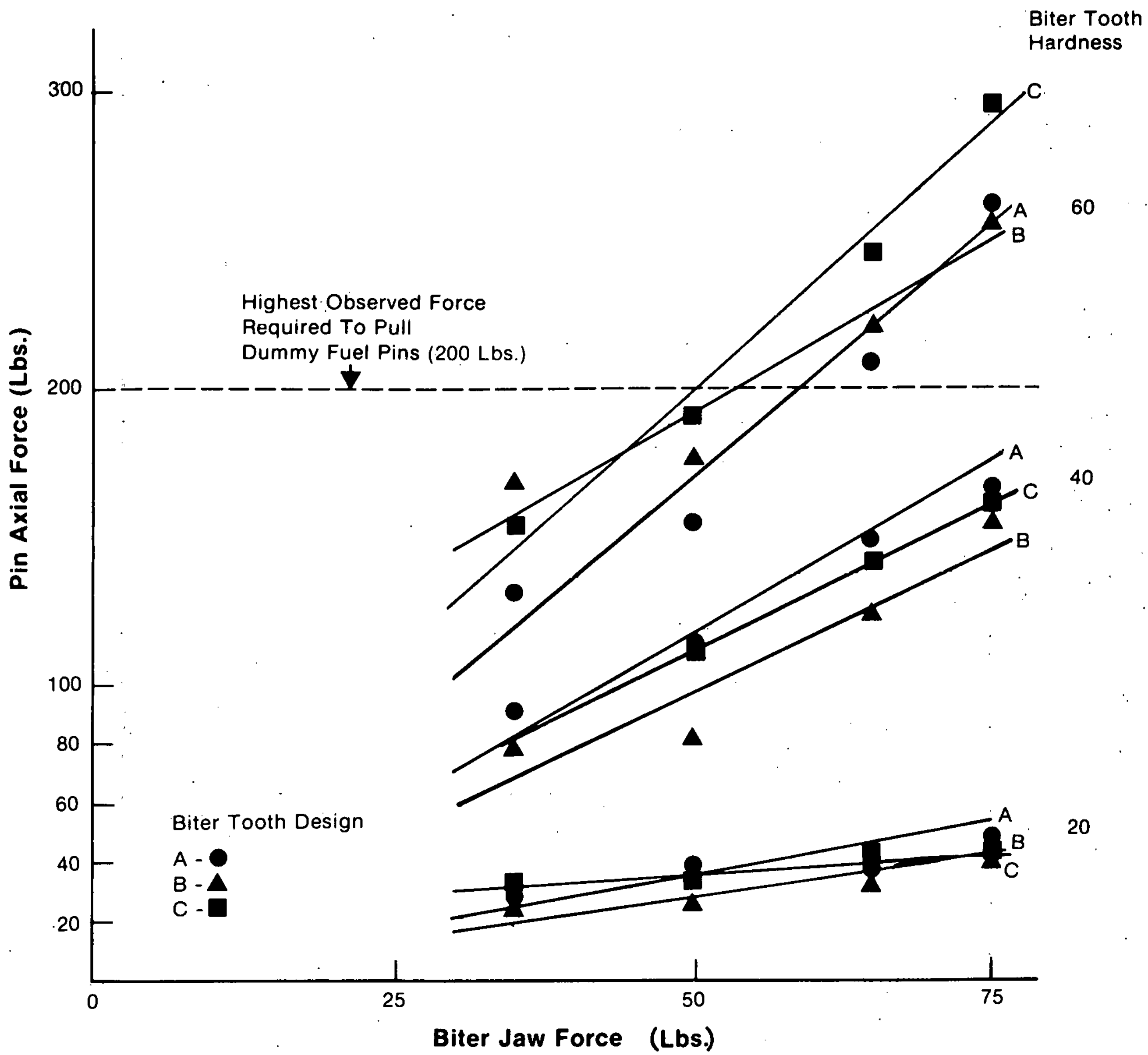
It was found that biter tooth pairs as shown in Figure 3-1 with the following characteristics worked within this 200- to 350-pound range when operated at a biting force of 70 pounds as an opposed pair:

- Hardness - 60 Rc
- Relief angle - 10°
- Rake angle - 30°
- Contoured to the pin radius
- Width one-third of the pin diameter.



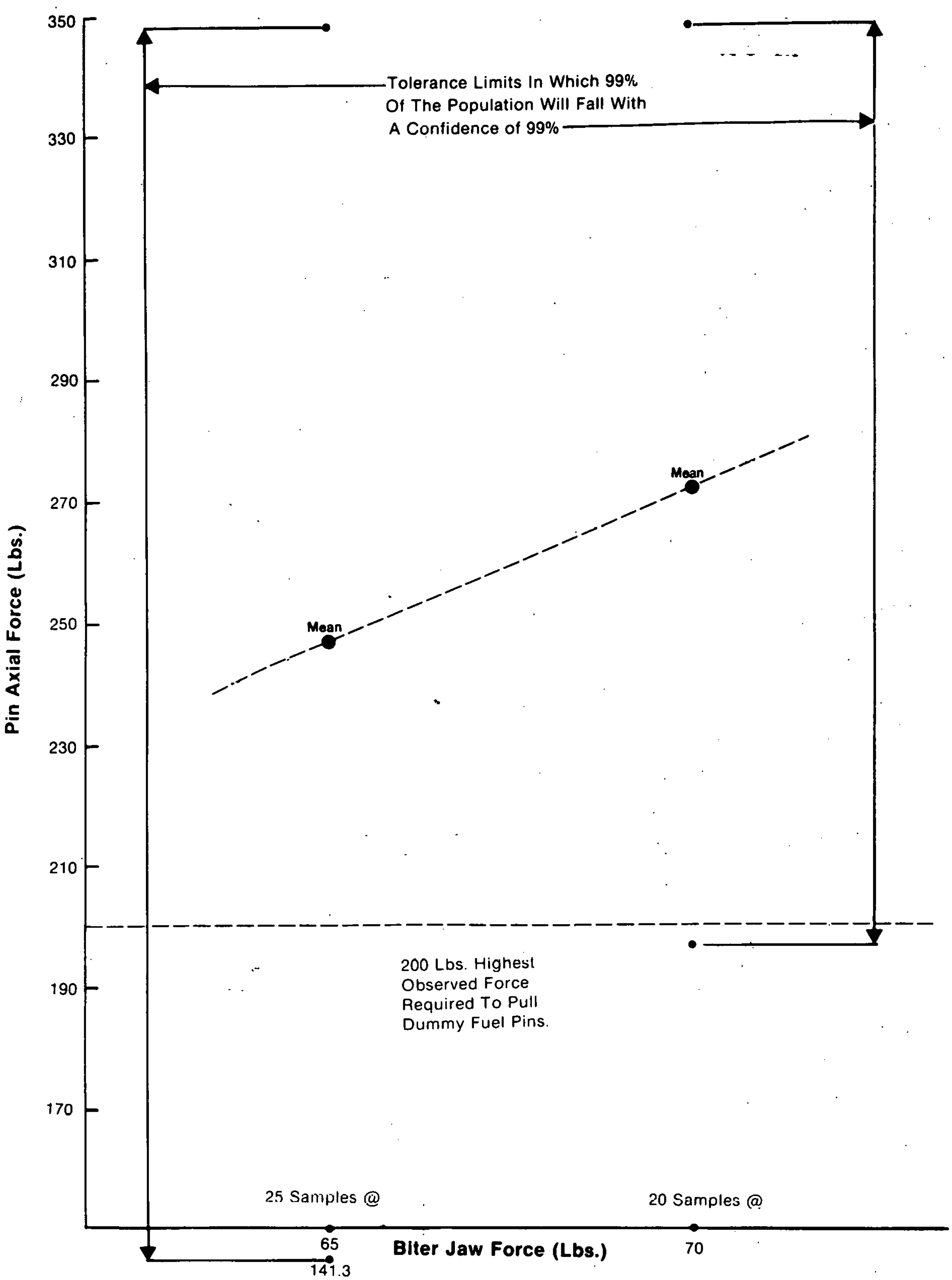
BITER PARAMETRIC TESTING SCHMATIC

FIGURE 3-1



DEVELOPED FUEL PIN PULLING FORCE VERSUS BITER FORCE FOR THREE BITER INSERT DESIGNS WITH EACH DESIGN TESTED AT THREE HARDNESS VALUES

FIGURE 3-2



DEVELOPED FUEL PIN PULLING FORCE VERSUS BITER FORCE
FOR BITER INSERTS OF DESIGN "C", HARDNESS R_C60 (EXTENDED TESTING)

FIGURE 3-3

It was also noted that, in consideration of the various PWR cross-sectional designs (i.e., array size, pin diameters, etc.), individual puller heads that gang a number of biters equal to the pins per row would be required in practice. These puller heads would be interchangeable depending on the type fuel assembly to be processed but could all be operated with a single pulling bed. In any case, the bed would need to develop a pulling force of 5000 pounds.

4.0 FUEL PIN VENTING AND SEALING

4.1 Purpose

Disassembly of fuel into individual pins opens several new and unique fuel handling possibilities. For example, inspection and cleaning is facilitated by ready accessibility to all exterior surfaces of the fuel pins. Another possibility, and one which has been explored at AGNS is the removal of the fission gases from the gas plenum contained at the end of each pin.

Most nuclear fuel is prepressurized with helium fill gas during fabrication. Fission gases generated during burnup in the reactor core combine with the fill gases. The cladding which functions as a small pressure vessel, is stressed at the end of fuel life by the gas pressure. The material stress may be in the range of 5 to 10,000 psi with typical internal pressures of around 800 to 1100 psi. Due to the likely degraded condition of the cladding, there is a possibility of periodic failure of the individual pins during long term storage. One possible alternative is to deliberately remove the fission gas by puncturing each individual pin, thereby totally depressurizing the fuel plenum. The fission gas can be uniformly collected and treated at one place. If a means can be found for resealing the fuel rod, containment and, hence, considerably safer storage of the actual fuel pellets within the cladding is assured for an extended storage period.

A technique to accomplish both puncturing, gas venting, and sealing is being developed at AGNS. The two principal devices employed are a low power pulsed laser and a sealed transparent chamber. The chamber can be either evacuated (to vent gases) or slightly pressurized (a cover gas for welding is desirable). The process can be directly integrated with fuel disassembly. Only a modest incremental increase in operational time occurs (less than one hour to process all pins). The use of one device, the laser, to both puncture (or drill) the tube and then reweld it, is accomplished by simply varying the laser beam strength and the optical parameters. Rewelding (resealing) does not require the addition of a filler metal. The optical laser requires that only a bare minimum of machinery be located in the contaminated hot cell (directional mirror and focusing lens). The process can be readily automated.

4.2 Results

A series of prototype tests was conducted in the laboratories of a laser designer and vendor (Laser Incorporated, Sturbridge, Massachusetts). Both drilling and rewelding operations were successfully performed on a repeatable basis. The tests were performed on both stainless steel and zircaloy tubing. Tubing dimensions were comparable to that of LWR fuel cladding. The initial tests consisted of refining the parameters of laser power, pulsing rate, hole size, and beam optics. Later studies focused on assuring repeatability and consistency with a large number of samples.

The following results were observed:

(1) Optimal hole diameter appeared to be approximately 0.010 inch in tubing with a 0.026 inch wall thickness.

(2) Rewelding of the tube resulted in a new wall thickness of at least 0.018 to 0.020 inches which is about 75% of the original wall thickness. Use of a cover gas prevented oxidation of the cladding and resulted in a superior seal weld.

(3) The cycle interval between each individual drill or reweld operation was about three to five seconds. Most of this time was employed for repositioning the fuel. The recycle time of the pulsed laser is one second.

(4) Repeatability between successive operation was excellent. Assurance of puncture or rewelding appeared to be 99+%. The success was due to both the consistent operation of the laser and the use of a milling machine table with a numerically controlled programmer. The latter assured the accurate placement of the fuel.

(5) The heat-effected zone of the rewelded area is limited due to the intense focused heat of the laser beam and the short pulse duration.

4.3 Conclusions

The work to date has focused on verifying the feasibility of the process. An additional test required is the drilling of pressurized tubes. This will verify if tearing action occurs to the metal during drilling. It is suspected that the short time constant and the intense localized heat of the laser precludes this. Additional tests will be required to develop optimal hole size under pressurized conditions to assure both adequate venting of gas and a hole suitable for rewelding. Additional testing and development will be required to integrate the process with the disassembly operation. Techniques for adequately directing the flow of fission gas to the plant off-gas system for further processing will require development.

In summary, preliminary test work has shown that the process will work in an ideal laboratory setting. Future development is needed to implement the process as a fuel handling alternative. If fuel is to be handled without reprocessing for either long term storage or for outright "throwaway," a means of assuring confidence in the stability of the radioactive material is mandatory. The technique of laser drilling and welding provides a practical means of eliminating fission gases from the fuel pins and stabilizing the cladding integrity.

5.0 FUEL PIN REMOVAL DEVELOPMENT

5.1 Purpose

After the end fitting is removed, the biter is engaged and the fuel pins are removed from the fuel assembly to accomplish disassembly. The fuel pin is retained in the assembly skeleton by the spacer grid via friction to allow for growth in the reactor. It is these friction forces that must be overcome to remove the fuel pin axially.

Dismissing thermal or mechanical processes to cut the spacer grids from the fuel pins as complex, pushing or pulling axially appeared to be the alternatives available for pin removal. After a qualitative review of these processes, pulling was selected as the desired method to implement. (Pushing introduces the additional step of bottom end fitting removal and the threat of fuel pin buckling.)

In concert with development of means to engage the pin as previously discussed in Section 3.0, it was necessary to define the range of forces required to pull pins from various fuel assembly types. Also, to support statistical extrapolations from the limited data that could be generated on a practical number of pulling tests, an investigation was made to confirm the assumed normal distribution of individual pin pulling forces from a prototypical fuel assembly.

5.2 Results

To fix the range of pin pulling forces, the three available PWR prototypical fuel assemblies (see Table 5-1) were utilized. Note 2 of Table 5-1 indicates that all pins were not pulled but that "worst case" pins were tested. Preliminary testing had established that higher pulling forces could be expected adjacent to or between control thimble tubes in the pin array. The range of 20 to 200 pounds was established from the data shown in this table.

Irradiation effects will have an unquantified influence on these values. Previous work by others with irradiated fuel showed an upper limit of approximately 130 pounds. For example, thermal cycling should result in relaxation of spacer grid spring rate while "knuckling" and growth will increase physical dimensions; the first potentially lowers forces while the others offset this lowering to some degree. Therefore, for continuation of the effort, 200 pounds was established as a conservative design basis.

However, it was felt necessary to accommodate fuel pins that developed pulling forces in excess of 200 pounds. This could result either from normally unanticipated frictional forces or mechanical interferences. These interferences could develop from rare, though gross, cladding failures interfering with the spacer grids. Therefore, a pulling overload sensing system and a nonstandard alternate processing route were included in the system design criteria.

TABLE 5-1

FUEL PIN PULLING FORCE VARIATION AMONG VARIOUS DUMMY FUEL ASSEMBLY

Dummy Fuel Type	Individual Dummy Fuel Pin Pulling Forces (lbs.) Highest	Highest[1] Average	Lowest Average	%[2] of Tested Pins Exceeding 100 lbs. Average
1. Gulf United Nuclear (GUN) Westinghouse Reload 15 x 15	200+[4]	181	31	42%
2. Babcock & Wilcox (B&W) 15 x 15	105	95	26[3]	0
3. Westinghouse (WEST) 17 x 17	105	101	59	3%

NOTES:

(1) Three pulls were made on each pin. Generally, forces increased with each of the three pulls.

(2) Assuming the higher pulling forces to develop at those pins adjacent to or between thimble tubes, the selected pins were chosen to measure the higher expected pulling forces. The percentage of pins tested were as follows: GUN-6%, B&W-7%, and WEST-13%.

(3) This is next-to-lowest. Lowest was considered erroneous data.

(4) Scale limit was 200 pounds.

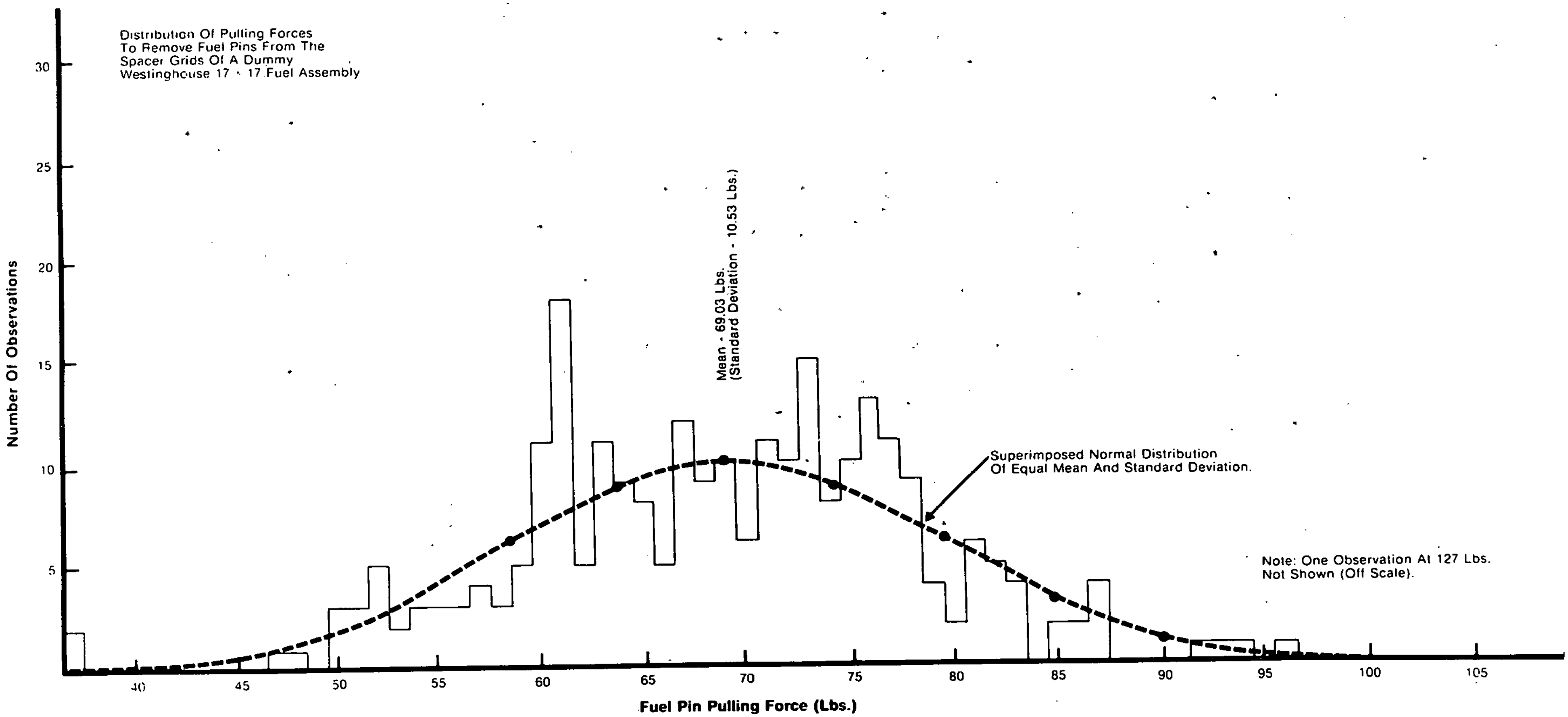
The assumption of a normal distribution of the pulling forces from a single assembly was confirmed as can be seen in Figure 5-1. The figure is a histogram of the pulling forces from the Westinghouse 17 x 17 dummy fuel assembly. Here all pins were pulled three times each and the forces averaged for the three pulls. A normal distribution is superimposed to show the correlation using dashed lines. The note indicates one observation at 127 pounds was beyond the range of the figure. This, once again, reinforces the requirement for a nonstandard alternate processing route.

5.3 Conclusions and Recommendations

The pulling force range of 20 to 200 pounds appears conservative, but a nonstandard alternate processing route must be included in a disassembly/canning system. An assumption of a normal distribution for pulling forces for all the fuel pins of a given assembly was confirmed.

An assembly from the third major supplier of initial load PWR fuel, Combustion Engineering, was not available during pulling force testing. Efforts are underway to obtain such a test assembly.

An investigation of irradiation effects as they impact pulling forces in particular and disassembly and canning in general are planned. The intent would be to simulate these effects in prototypic fuel components, to perform additional testing, and to refine the previously collected data accordingly.



DISTRIBUTION OF PULLING FORCES TO REMOVE FUEL PINS FROM
THE SPACER GRIDS OF A DUMMY WESTINGHOUSE 17 x 17 FUEL ASSEMBLY

FIGURE 5-1

6.0 FUEL PIN CAN LOADING DEVELOPMENT

6.1 Purpose

The pins from the Westinghouse 17 x 17 and the Babcock and Wilcox 15 x 15 dummy fuel assemblies were useful in establishing approximate collector trough slopes and studying pin loading forces. Increasing the number of pins has the potential to increase the chances for random crossing during gravity loading of the trough. The random crossings in turn have the potential to interfere with level loading of the trough and level loading facilitates pin bundle loading into the can. It was, therefore, desired to establish a slope angle that resulted in level trough loading regardless of fuel type or trough cross section that was being loaded.

When loading the pin bundles into a can of a given cross-sectional area, two parameters affect the resulting forces. One is the total end view area of the pins with pin-to-pin contact in a square array; the other is the increase in this area under the random stacking and crossings that develop when the gravity collection system is used. The first is a function of the number of pins and their individual diameters. The Babcock and Wilcox 15 x 15 assembly is a "worst case" square array (i.e., greatest total area) for typical PWR fuel even with only 208 pins. The Westinghouse 17 x 17 with 264 pins has a lower square array area but tends, with more pins, to increase crossings during pin collection. Therefore, the primary concern was to see what limits could be placed on loading forces for selected trough cross sections when loading the pin bundles from these assemblies, each of which constitutes a "worst case" for one of the parameters.

If one defines "packing fraction" as the ratio of the end-view area of a can section to the square array area of the pins being loaded, one has an indication of the free area available to accommodate crossing. For both options (i.e., the square, two-section, pool can and the round, three-section truck cask can), the "packing fraction" for the Babcock and Wilcox dummy pins was 1.03.

In actual practice, additional free area can be created by a random number of pins collecting into a triangular array where this array requires only 86.7% of the area of the square array. Pockets of triangular arrays can be noted in Figure 1-6. Even though other trough cross sections were known to lower loading forces, a rectangular trough was selected as compatible with a variable area can to investigate the relationship between packing fraction and loading forces. This relationship should provide insight into expected loading forces for cans with packing fractions different than those used in this development work.

6.2 Results

Figure 6-1 shows the apparatus used to establish the collector trough slope. Note that the sloping surface is pivoted via a bolt and adjustable within the limits of the slotted link at the right. It is shown with the 45° trough used to load square cans but was also used with a 120° trough to load round cans. Within the visual observations made, it appears that a collector trough slope of 8° is adequate either for the 264 pins from the Westinghouse dummy or the 208 pins from the Babcock and Wilcox dummy.

Figure 6-2 shows the results at 3.6° of collector slope. Note that the pins collect preferentially on the right side of the trough.

Figure 6-3 shows the results at 8.25° where the cross section is more level than in the previous figure.

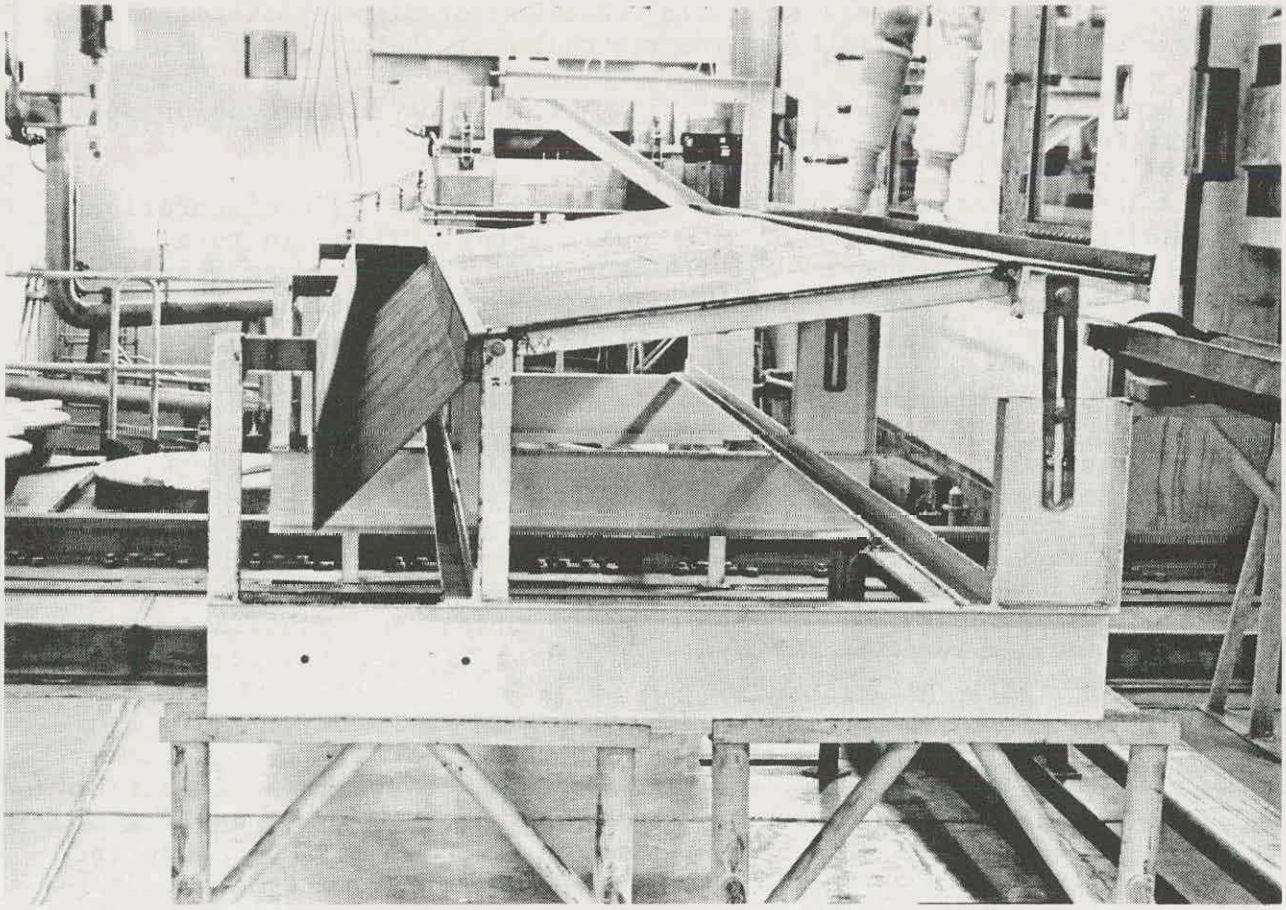
It was found that the 45° and 120° trough cross section configurations tended to increase pockets of triangular array. This, in turn, generated free area to accommodate the increased pin bundle area resulting from random pin crossing. This decreased the amount of pin bundle reshaping required during can loading. This, in turn, lowered pin loading forces. Therefore, the 45° and 120° trough sections were selected, respectively, to load square and round cans.

Figure 6-4 shows the square can after loading from the 45° trough, and Figure 6-5 shows the round can after loading from the 120° trough.

An upper limit of 1300 pounds covered all observed loading forces for the square can and 1400 pounds for the round can. This is with corrections applied for the fact that the hollow Babcock and Wilcox dummy pins and the ceramic filled Westinghouse pins were lighter than comparable pins with uranium oxide pellets.

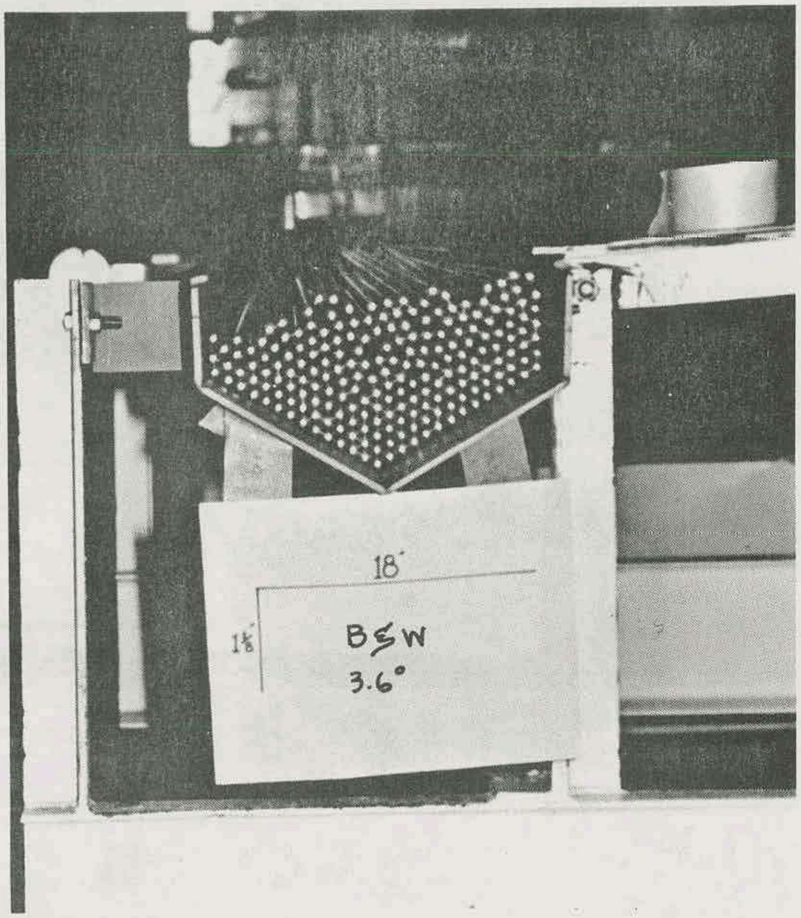
Table 6-1 shows the results of the pin loading tests. These results are not corrected for weight differences. However, the weight corrections do not change the observed higher forces for the Westinghouse 17 x 17 pins. Therefore, even though these pins had an approximate 5% advantage on packing fraction for each can, they still required higher loading forces. This indicates that, within this range, the approximately 20% increase in pin number favoring increased random crossings offsets the 5% packing fraction advantage.

The notes at the bottom of this table indicate that more development work is required to refine the design of the forming surface that shapes the approximately level top surface of the free pin bundle in the 120° trough to the can radius as it enters the can. This was a passive member during the testing. Lower angles, coatings to lower the coefficient of friction between this surface and the pins, and active forming surfaces are being considered. Similar work is required with the 45° trough where the forming surface provides final leveling and conforms



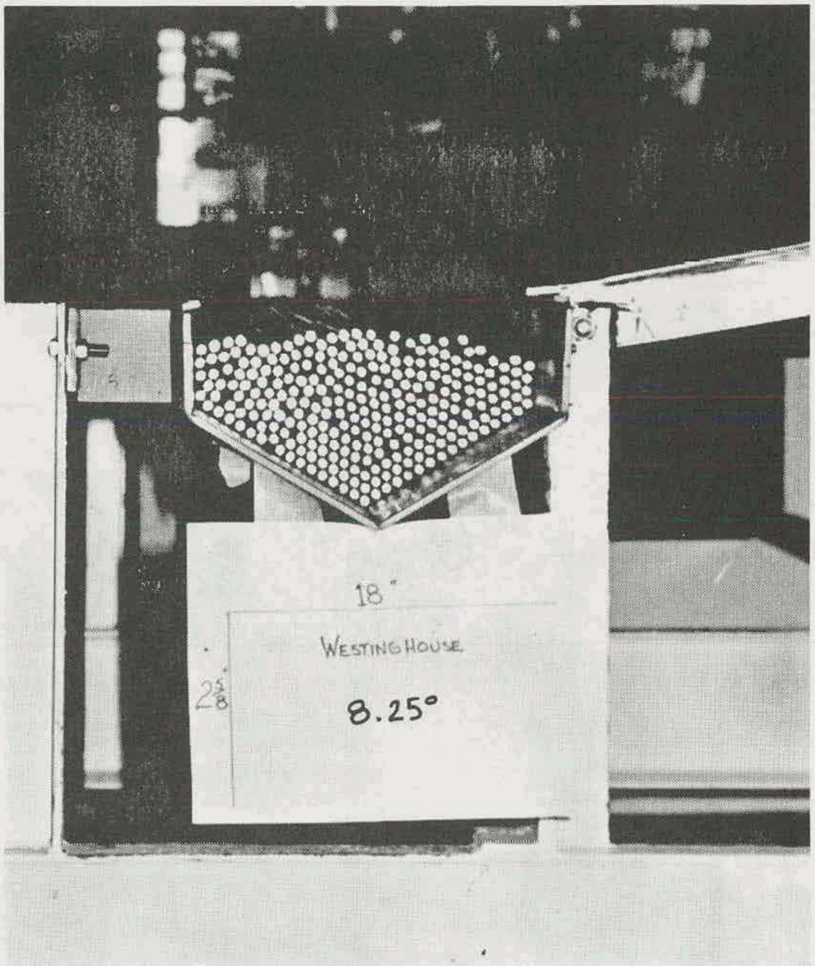
FUEL PIN COLLECTING AND LOADING TEST DEVICE

FIGURE 6-1



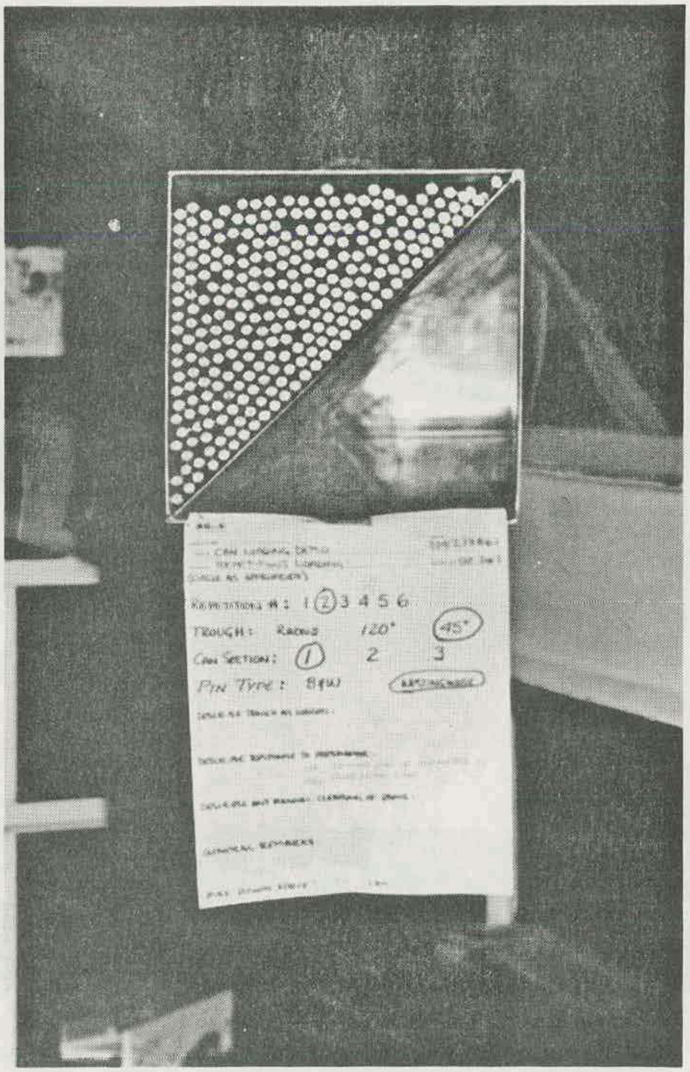
3.6° COLLECTOR SLOPE PIN STACKING RESULTS

FIGURE 6-2



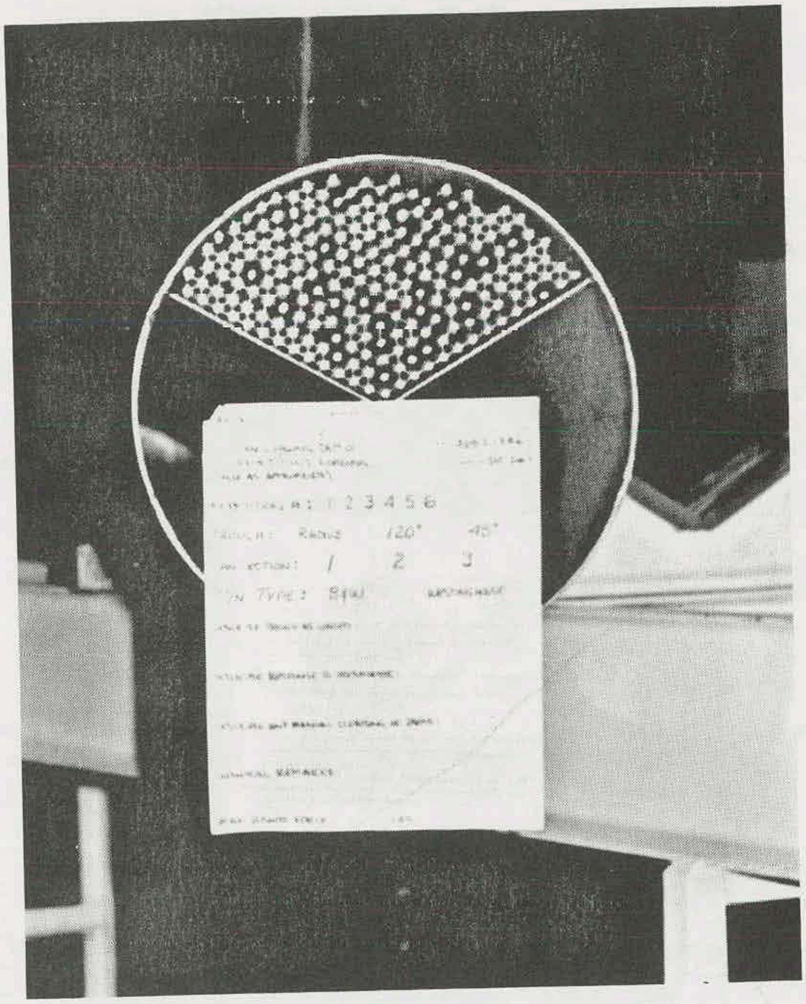
8.25° COLLECTOR SLOPE PIN STACKING RESULTS

FIGURE 6-3



SQUARE CAN LOADED USING 45° TROUGH

FIGURE 6-4



ROUND CAN LOADED USING 120° TROUGH

FIGURE 6-5

TABLE 6-1

CAN LOADING FORCE DEMONSTRATION

		Pusher Force to Load Fuel Pins in Can (lbs.)			
		Square			
		Round			
Trough Cross Section↓	Fuel Pin Type ↓	Section 1	Section 2	Section 3	Average
120°	Westinghouse 17 x 17	850	1175[1]	1100[2]	1042
	Babcock & Wilcox 15 x 15	900	800[1,3]	1050[2]	917
Radius	Westinghouse 17 x 17	1475	1675[2]	1675[2]	1608
	Babcock & Wilcox 15 x 15	800[2]	1100[1]	800[3]	900
45°	Westinghouse 17 x 17	900	1100	N.A.	1000
	Babcock & Wilcox 15 x 15	900	900	N.A.	900

NOTES:

(1) Manual clearing of bowed pins required.
(2) Manual clearing of jammed pins required due to trough-can misalignment.
(3) Tried vibration of pins to facilitate loading.

the bundle limits to the can section dimensions. Also, the demonstration equipment highlighted the requirement for can and can section as well as trough-can alignment tolerances.

Figure 6-6 shows a schematic of the rectangular loading trough and the variable-area can used to investigate variable packing fractions. The top surface of this can was adjustable permitting variations in its cross-sectional area. This permitted packing fraction variations.

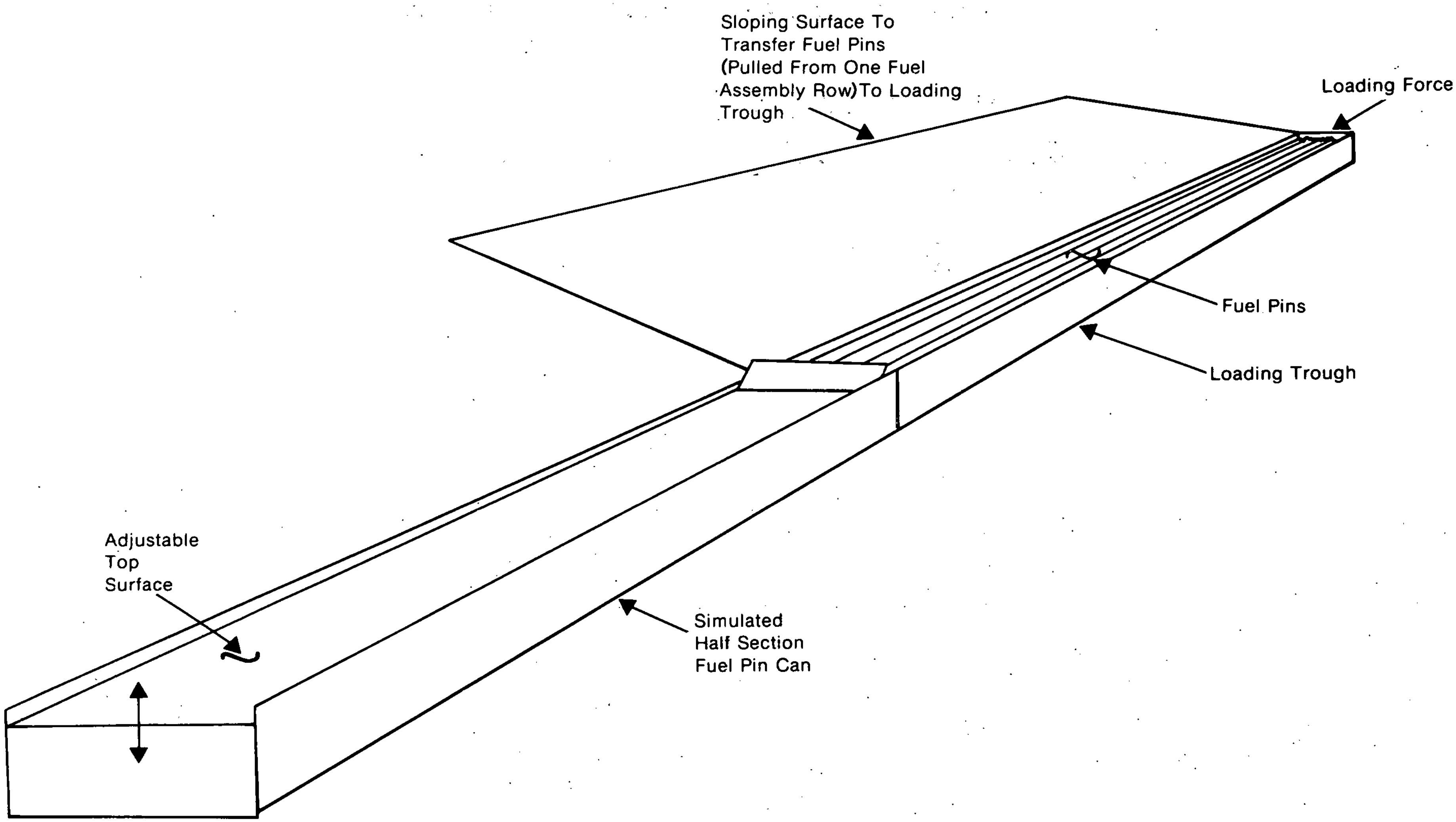
The results of the variable packing fraction testing are shown in Figures 6-7 and 6-8. As would be expected, loading forces tend to increase at an increasing rate as packing fractions decrease. Note that after correcting for weight differences (i.e., superimpose asymptotes) and aligning common values on the abscissa, a given packing fraction of the smaller number of pins (i.e, Babcock and Wilcox 15 x 15) is much easier to load.

6.3 Conclusions and Recommendations

It was found that a collector slope of 8° tended to level the profile of the free pins in the collection troughs. Utilizing this slope, it was found that selected trough cross sections of 45° for square cans and 120° for round cans preshape loose pin bundles so that loading forces do not exceed acceptable levels (less than 1500 pounds) and mechanical jams are minimized.

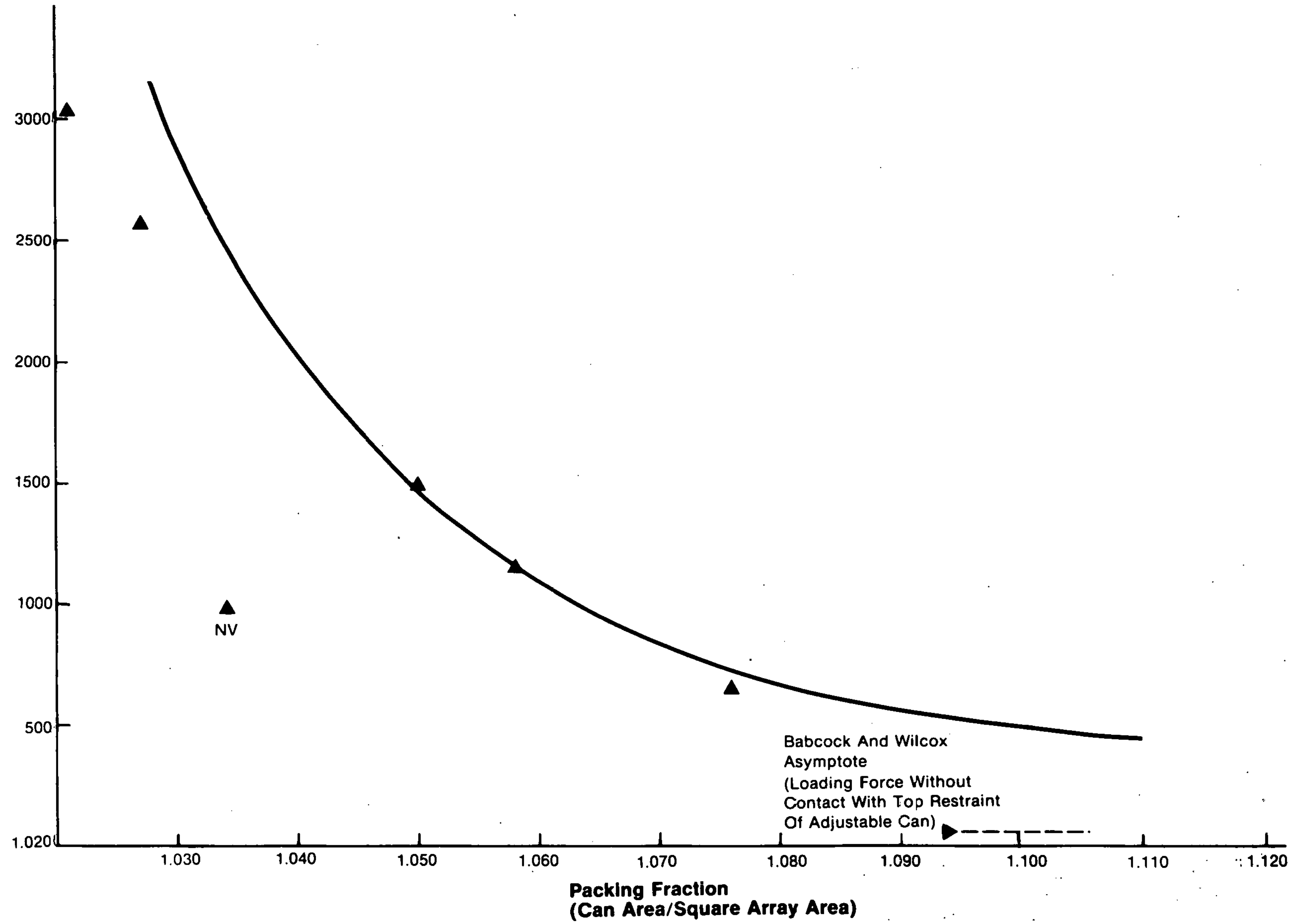
It is also recommended that these results be confirmed with pins that simulate the weight of UO_2 fuel pins. Weight is expected to be an important parameter in fixing collector slope angles as well as random crossings of pins during loading.

Further development work will also be necessary at the trough/can interface to preclude individual pins interfering with the loading of the bundle. Forming surface development and controlled interface tolerances should accommodate these concerns.



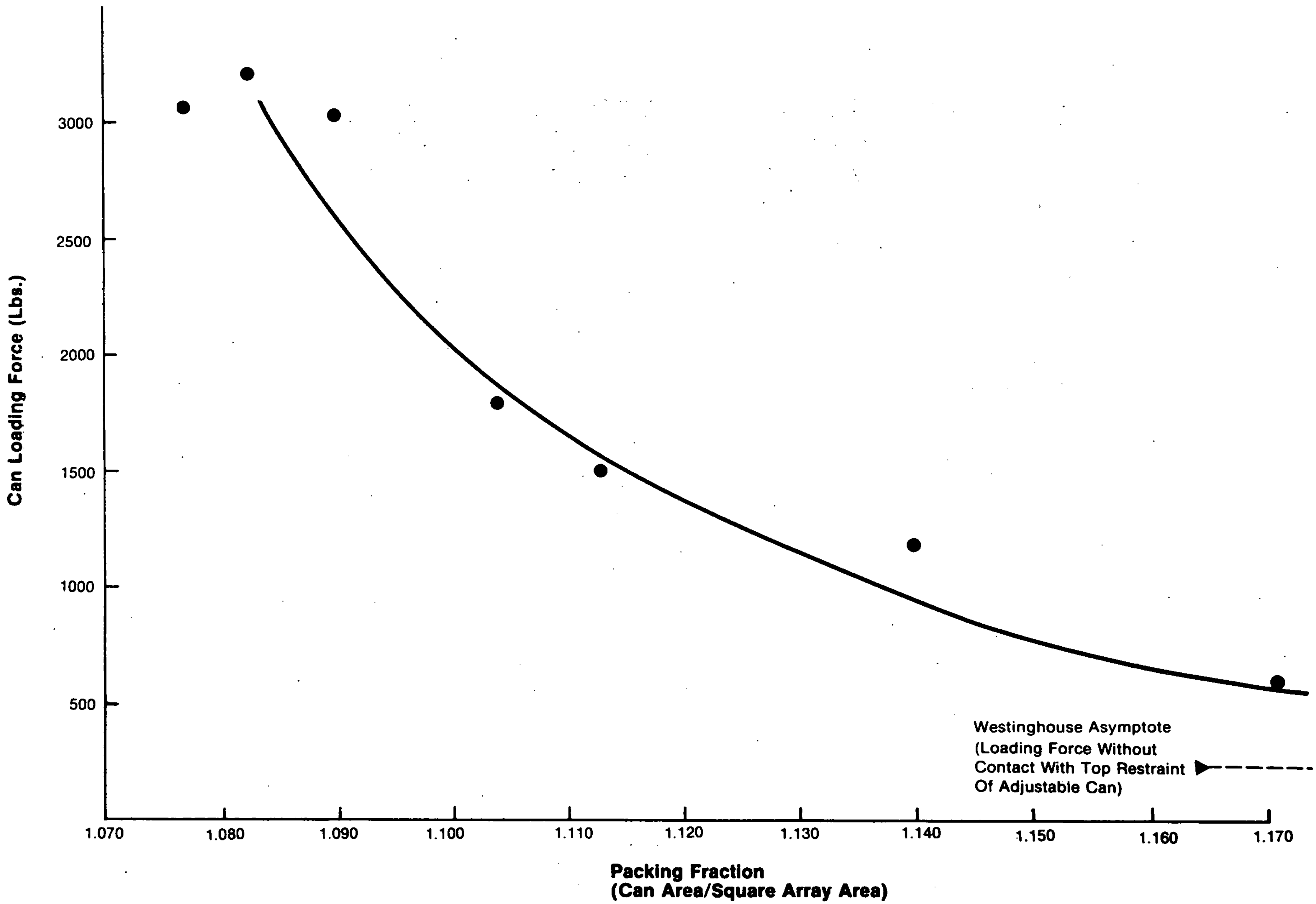
VARIABLE PACKING FRACTION TEST SCHEMATIC

FIGURE 6-6



ADJUSTABLE CAN DEMONSTRATION - BABCOCK AND WILCOX
15 x 15 DUMMY FUEL PINS (350 POUNDS TOTAL WEIGHT)

FIGURE 6-7



ADJUSTABLE CAN DEMONSTRATION - WESTINGHOUSE
17 x 17 DUMMY FUEL PINS (640 POUNDS TOTAL WEIGHT)

FIGURE 6-8

7.0 INTEGRATED SYSTEM DEVELOPMENT

7.1 Purpose

The integrated system development for disassembly and canning processes consisted of hardware demonstrations.

One hardware demonstration consisted of defining the problems associated with transfer of an intact dummy fuel assembly through the remote cells. This would be required if the process was installed in the remote support cell in a development mode.

Another demonstration consisted of the integration of as many steps as feasible in a disassembly and canning process to provide an initial estimate of throughput capacities.

A fuel assembly transfer system to convey fuel from the storage pool to the remote cell already exists. It is usable "as is" in a disassembly/canning process. Combining it with the various existing hardware items generated via component development while using estimated processing times for components not yet manufactured, a review of throughput time was made.

7.2 Results

The dummy fuel transfer demonstration showed that for LWR fuel assemblies in excess of 150 inches vertical transfer through the headend would require equipment modification in the vicinity of the delivery position in the remote cell. Up to 180-inch lengths could be handled in the rest of the headend vertically. Utilizing horizontal movement from the delivery position as is the design intent of the existing fuel transfer table, complete transfer is now demonstrable.

Demonstration of a loaded can fit in a simulated rack section was successful with a nominal 1/4-inch total clearance either direction. However, this appears to be a minimum clearance. A practical working clearance will need further demonstration. This can-fit demonstration was combined with a system demonstration integrated to the extent then possible and reaffirmed the projected processing rates of 12 to 15 assemblies per day.

7.3 Conclusions and Recommendations

Transfer of an intact fuel assembly through the headend spaces is feasible.

Under Option 1 a pin-filled can can be loaded into a pool storage rack section with a tolerance of 1/4 inch total either direction.

At this stage in the design and component development, there are no apparent obstacles to realizing processing rates of 12 to 15 assemblies per day in a fuel disassembly/fuel pin canning process in the BNFP headend spaces.

8.0 SYSTEM DESIGN DEVELOPMENT

8.1 Purpose

To ensure adequate space and viewing requirements could be met, initial equipment layouts for both the disassembly and canning options were made. Initial design concepts to support these layouts were established to define the spatial envelopes of the individual equipment items that would constitute the integrated system.

8.2 Results

The layout of the integrated system for Option 1 (i.e., square canning of fuel pins for increased pool storage) is shown in Figure 8-1. The process flow follows the numerical order of equipment labels.

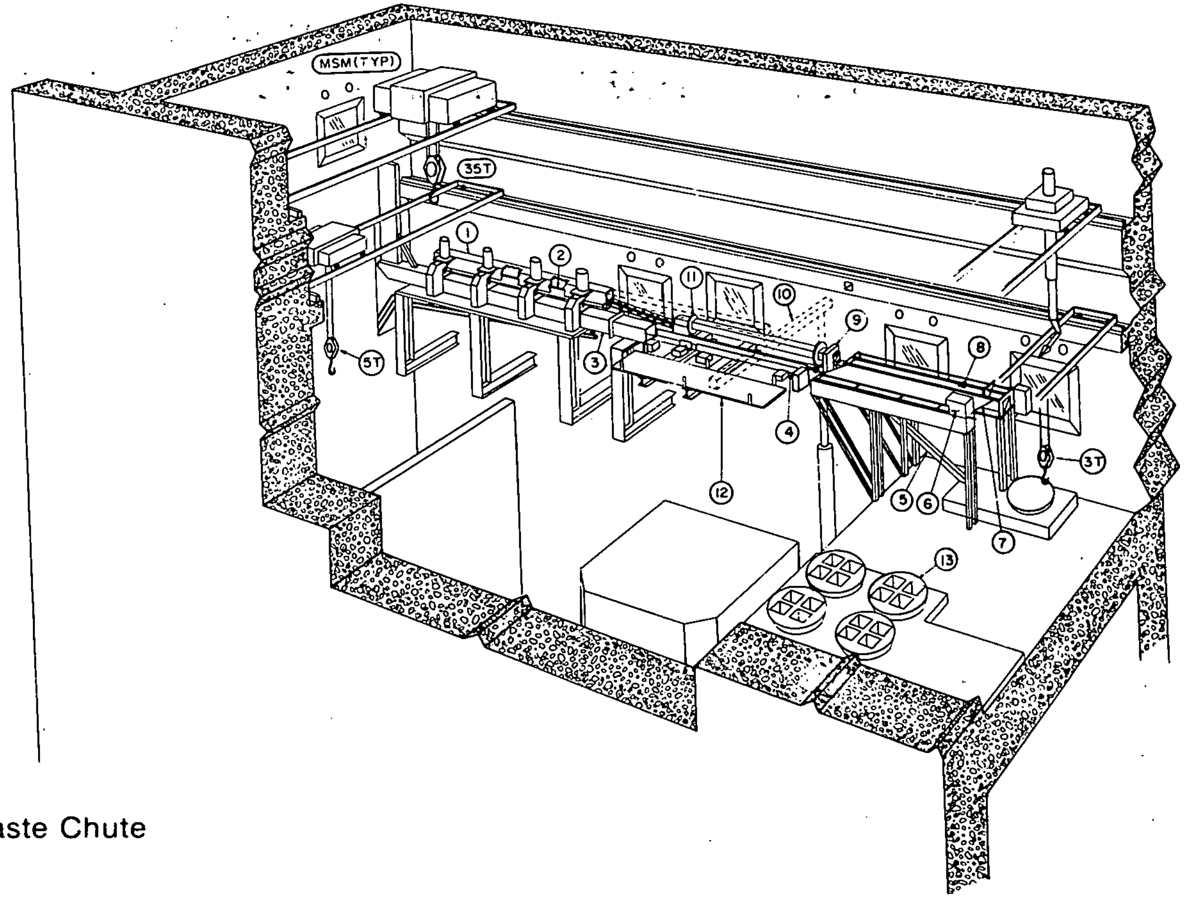
Option 1 to increase pool storage was arranged for horizontal process flow. After delivery of the fuel assembly horizontally in the remote cell, this process translates the fuel assembly approximately four feet perpendicular to the delivery axis. The process then moves the fuel in the direction of its lengthwise axis for end fitting removal and fuel pin removal by rows. During the fuel pin collection for can loading, the process translates the fuel pins back to the delivery axis. The pin bundle is loaded into a half section of a square can. A second assembly is processed similarly to load the other half section. Then, the filled can is capped and reloaded into the delivery system which is reversed to carry the compacted fuel back to the pool for storage. Now the pins from two assemblies are stored in a pool rack section in which one fuel assembly had been previously stored.

The layout of the integrated system for Option 2 (i.e, round canning of fuel pins for increased truck cask shipping capacity) is shown in Figure 8-2. Here again, the process flow follows the numerical order of the equipment labels.

Option 2 to increase truck cask shipping capacity was laid out also as a horizontal process. Fuel delivery, end fitting removal, and pin removal are identical for both options. However, during fuel pin collection under Option 2, the process centerline is translated an additional 3-1/2 feet from the delivery axis. This provides operational clearance so that the loaded can is unobstructed as it is reoriented from its horizontal loading position to its vertical handling position. The vertical position is necessary for delivery to the dry cask loading area.

Both options require off-line processes of:

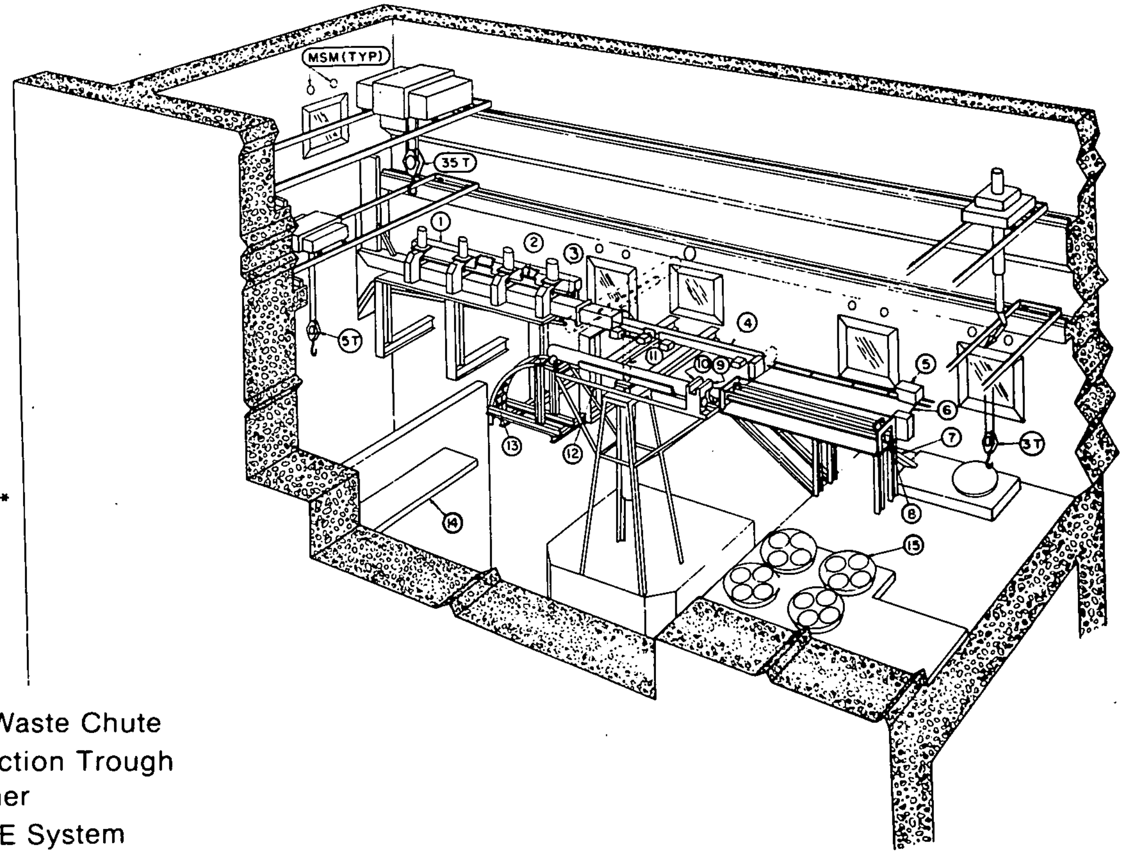
(1) A non-TRU solid waste system that compacts and packages the fuel assembly minus fuel pins (i.e., the cut end fitting and the fuel skeleton).



1 Fuel Transfer Conveyor*
2 Transverse Fuel Pusher*
3 Fuel Feed Magazine*
4 Fuel Holder
5 End Fitiing and Skeleton Waste Chute
6 Fuel PIn Puller
7 Fuel Pin Collector Surface
8 Fuel Pin Loader and Collector Trough
9 Fuel Pin Can Cap Positioner
10 Empty Can Positioner
11 Fuel Pin Can Holder
12 Non-standard Fuel Holder
13 Filled Can Temporary Storage
* Existing

DISASSEMBLY AND CANNING SYSTEM TO INCREASE POOL STORAGE - OPTION 1

FIGURE 8-1



1 Fuel Transverse Conveyor*
2 Transverse Fuel Pusher*
3 Fuel Feed Magazine*
4 Fuel Holder
5 Fuel Pin Puller
6 Fuel Pin Collector Surface
7 End Fitting and Skeleton Waste Chute
8 Fuel Pin Loader and Collection Trough
9 Fuel Pin Can Cap Positioner
10 Can Cap Welder and N D E System
11 Empty Can Positioner
12 Fuel Pin Can Holder
13 Filled Can Righter
14 Non-standard Fuel Holder
15 Filler Can Temporary Storage
* Existing

DISASSEMBLY AND CANNING SYSTEM TO INCREASE SHIPPING CAPACITY - OPTION 2

FIGURE 8-2

(2) A "jammed-pin" assembly relocation system that allows nonstandard disassembly away from the normal processing area.

(3) An empty fuel can supply system that feeds and positions cans without remote crane assistance.

These were included in the layout effort of both options.

A non-TRU waste system utilizes the same cutting device that cuts off the forward end fitting. The fuel holder has an integral fuel assembly feed system that incrementally advances the skeleton (i.e, after removal of fuel pins) to this cutter. The cut segments consisting of thimble tubes, spacer grids, and back end fitting fall by gravity via a waste chute to the existing solid waste handling system in the headend.

The only component of the nonstandard processing system shown in these figures is a nonstandard fuel holder. This is a temporary holding station for fuel whose pins would not pull free in the normal process for whatever reason. From this holding station the fuel assembly is relocated to a work station in the remote support cell. Here each assembly will be handled on a case-by-case basis with a full inventory of both mechanical and thermal remote "hand tools" available.

An empty can supply system is also shown in both figures in phantom. The intent is that an automated system receive cans from a cold support area, reorient them to process, and position and secure them for loading. This frees the maintenance cranes and power manipulator from any process operation support except for a crane providing inter-cell transfer of filled cans under Option 2. This precludes process interference of these maintenance units as well as unnecessary wear and tear which would compromise their "ready-standby" status for maintenance.

8.3 Conclusions and Recommendations

The system layout and design development has shown that adequate space and remote viewing does exist in the remote cell for the installation of a fuel disassembly/pin canning process for either option. It further indicates that the dedicated equipment concept for all process operations is feasible and that remote maintenance requirements are compatible with existing remote maintenance support equipment.

REPORT NO. AGNS-35900-1.2-45

SPENT FUEL DISASSEMBLY AND CANNING PROGRAMS AT THE BARNWELL NUCLEAR FUEL PLANT (BNFP)

APPENDIX A

FRICTION SAWING TESTS

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October 1979

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APPENDIX A TABLE OF CONTENTS

FIGURES

TABLES

1.0 FRICTION SAWING TESTS

During this program, various cutting arrangements were utilized and a range of operating parameters were investigated to establish workpiece feed and cutting rates, saw band speeds, and spacing limitations between the vertical tube holding fixture plates. The band wander, chip and fines accumulation, and burr configuration and characteristics were recorded and photographs were taken to document the setup and various results.

The holding fixture, as shown in Figure 2-2, was employed to arrange and hold the tube sections in the required configuration for cutting. The fixture was free to move across the friction saw table surface and was guided in a linear path to the saw band through the use of a deadweight pull fixture as shown in Figure A1-1. The deadweight pull fixture employed known weights which maintained the various workpiece pressures against the saw band during the cutting tests. The fixture halves were positioned with space between their vertical surfaces to allow cut measurements and to provide surfaces with which to contain the swarf during the actual cutting.

Chip and fines collection was achieved by the use of a shroud over the fixture (Figure A1-2) to collect swarf ejected from the tubes. A slotted cup was fitted under the table and around the sand band to catch particles carried by the saw band.

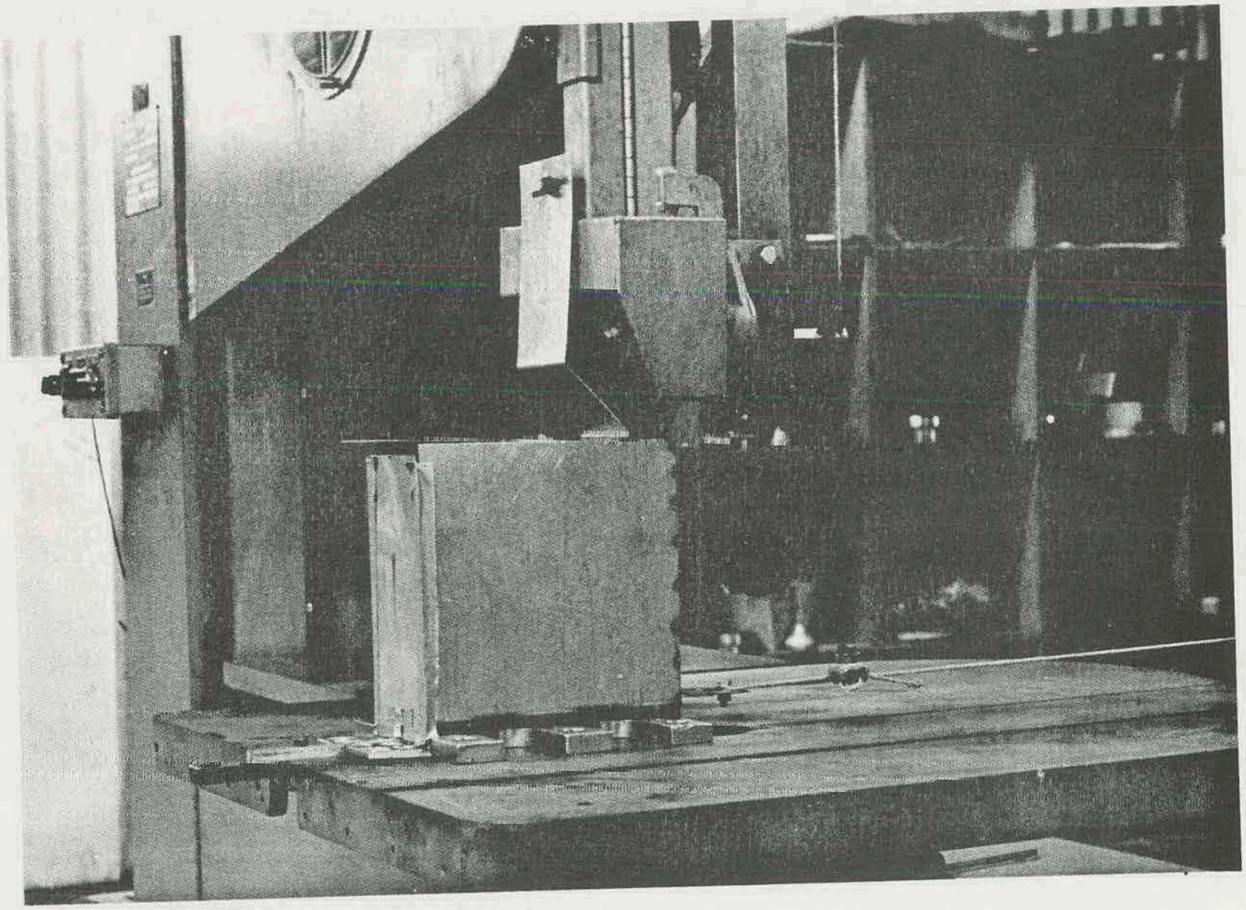
A commercial friction sawing machine was purchased from the Do-All Company and installed in the shop area permitting flexibility and application modification testing during the program. The machine is a Zephyr Model ZR3620 variable-speed type with a 3000 to 15000 feet per minute saw band speed range. The machine is powered by a direct-drive, 10-hp, 1800-rpm, 460-volt motor. The friction saw bands are standard vendor-supplied stock items, 0.035-inch thick by 1 inch wide. Both 10-pitch and 14-pitch saw bands were used in the test.

The tubes employed in the tests were seamless, Type 304, annealed stainless-steel with 5/8-inch outside diameter and 0.035-inch wall thickness.

2.0 TEST PROCEDURES AND RESULTS

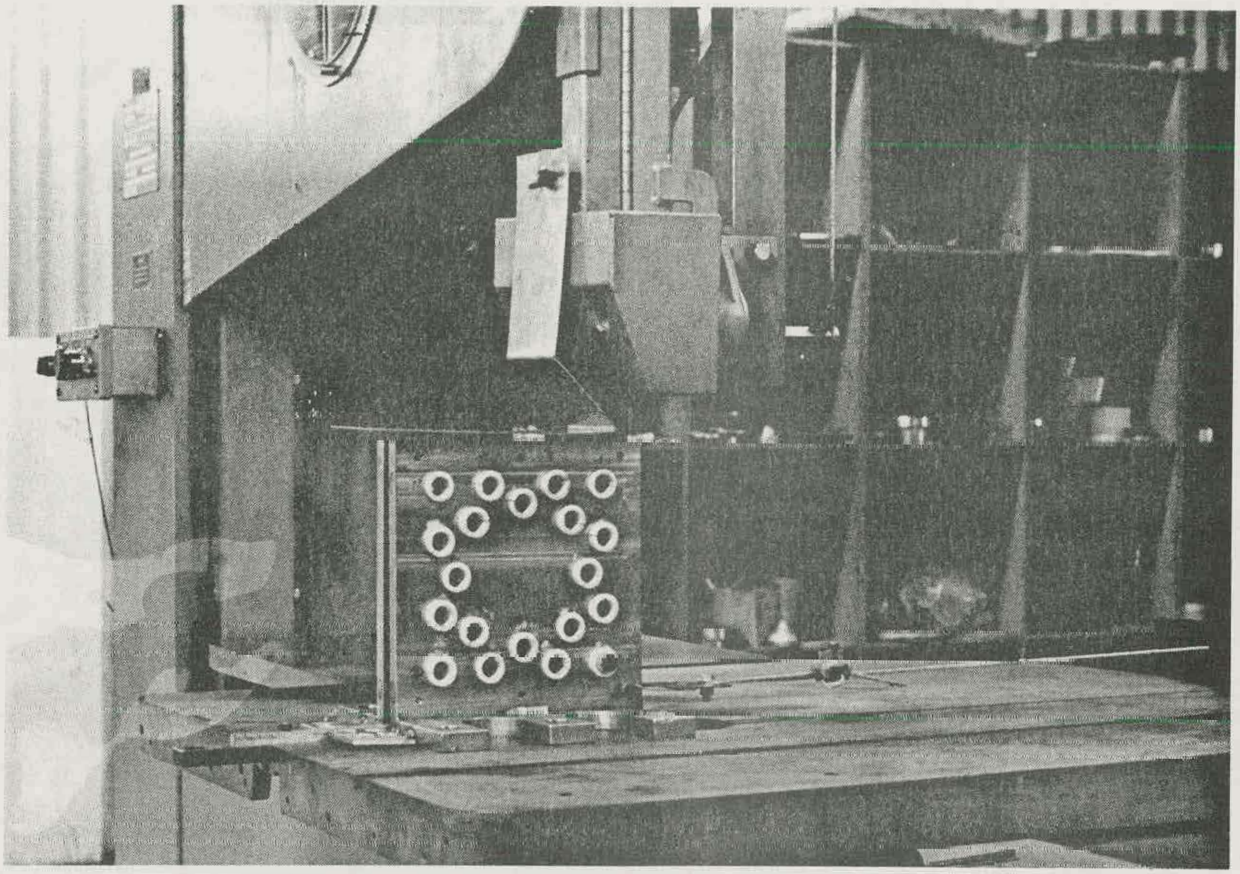
The initial and replication tests were all performed using the twenty-tube configuration.

The testing was conducted using a random sequence of sixteen test parameter combinations (see Figure A2-1) to eliminate sequence-related bias. These replicate cuts were sequenced at the beginning, middle, and end of the testing. Two replicate test cuts, based on the highest feed pressure and lowest blade speed and vice versa plus another arbitrarily



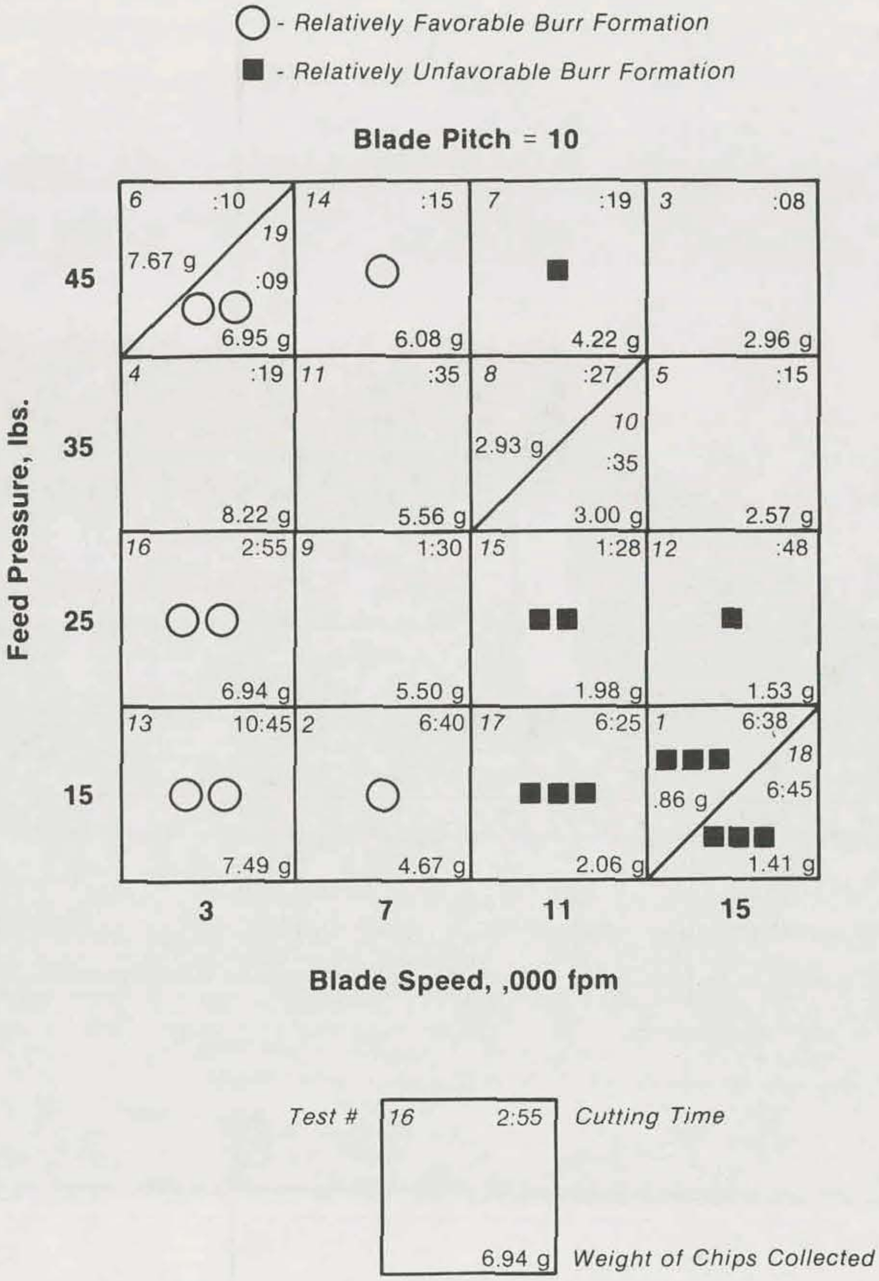
FIXTURE SETUP

FIGURE A1-1



FIXTURE WITH SETUP

FIGURE A1-2



Note: Tests with a fourteen pitch blade may indicate a very slight improvement over a ten pitch blade in burr formation; however, results are inconclusive.

FRICTION SAW EVALUATION

FIGURE A2-1

chosen one, were also included. The matrix was based on the following parameters:

- Blade Speeds - The high (15,000 FPM) and low (3000 FPM) limits of the saw speeds, the manufacturer's recommended speed (7000 FPM) for cutting thin wall stainless steel, and a low-friction saw speed (11,000 FPM) were chosen.

- Feed Pressures - A low value was established that would move the tube-loaded fixture across the saw band in ten minutes or less. The ten minutes was an arbitrary time chosen as a reasonable cutting time within a complete disassembly cycle. The upper value was considered to be the maximum pressure which would not break or damage the saw band. Two intermediate values were arbitrarily selected at ten-pound increments.

- Blade Pitch - Ten-pitch and fourteen-pitch blades were provided with the machine. A complete series of tests with three replications were run with the ten-pitch band; four tests were run with the fourteen-pitch band.

Generally, a review of initial test versus replication results established confidence that variability in testing technique had minimal impact on results. Results reviewed included the cutting time, burr formation, and amount of chips/fines collected.

In terms of burr formation, particle size and collectability, and cutting time, the most favorable sawing parameters utilize high-feed pressure and low-blade speed. This can be seen in the test matrix (Figure A2-1) and in the results of the sieve analysis of Table A2-1.

TABLE A2-1

SIEVE ANALYSIS

Particles obtained from the tests corresponding to the tested combinations of extremes on feed pressures and blade speeds in feet per minute (BFPM).

Test No.	Screen Size	% Retained	Cumulative % Retained
19	40	28%	
45 lbs. feed	80	65%	93%
3000 BFPM	100	3%	
	120	2%	
	170	1%	
	200	1%	
13	40	16%	
15 lbs. feed	80	70%	86%
3000 BFPM	100	7%	
	120	4%	
	170	3%	
	200	1%	
3	40	15%	
45 lbs. feed	80	58%	73%
15,000 BFPM	100	13%	
	120	7%	
	170	5%	
	200	1%	
18	40	17%	
15 lbs. feed	80	50%	67%
15,000 BFPM	100	9%	
	120	13%	
	170	8%	
	200	3%	

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SPENT FUEL DISASSEMBLY AND CANNING PROGRAMS AT THE BARNWELL NUCLEAR FUEL PLANT (BNFP)

APPENDIX B

LASER CUTTING TESTS

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October 1979

Allied-General Nuclear Services
Post Office Box 847
Barnwell, South Carolina 29812

APPENDIX B TABLE OF CONTENTS

FIGURES

1.0 LASER CUTTING TESTS

During the feasibility program, various cutting arrangements were utilized and a range of operating parameters were investigated to establish cutting rate, laser power requirements, gas jet nozzle positioning, and spacing limitations between the vertical surfaces of the tube holding fixture.

The holding fixture, as shown in Figure 2-2, was employed to arrange and hold the tube sections in the desired configuration for cutting. The fixture was securely attached to a flat movable table to permit translation of the tubes through the laser beam path at various controlled rates. The height of the table was adjustable to permit precise positioning of the laser beam focal point with respect to the workpiece surface. A typical setup is shown in Figure B1-1.

An existing concentric gas jet nozzle was included in the set-up. As shown on the accompanying photographs, it was positioned above the tube array with its position fixed with respect to the path of the laser beam. The nozzle included an orifice in its center through which the focused laser beam could pass and which established the gas jet flow pattern which was intended to be colinear with the laser beam path. The nozzle was constructed of solid copper and is cooled by the flow of gas through nozzle passages.

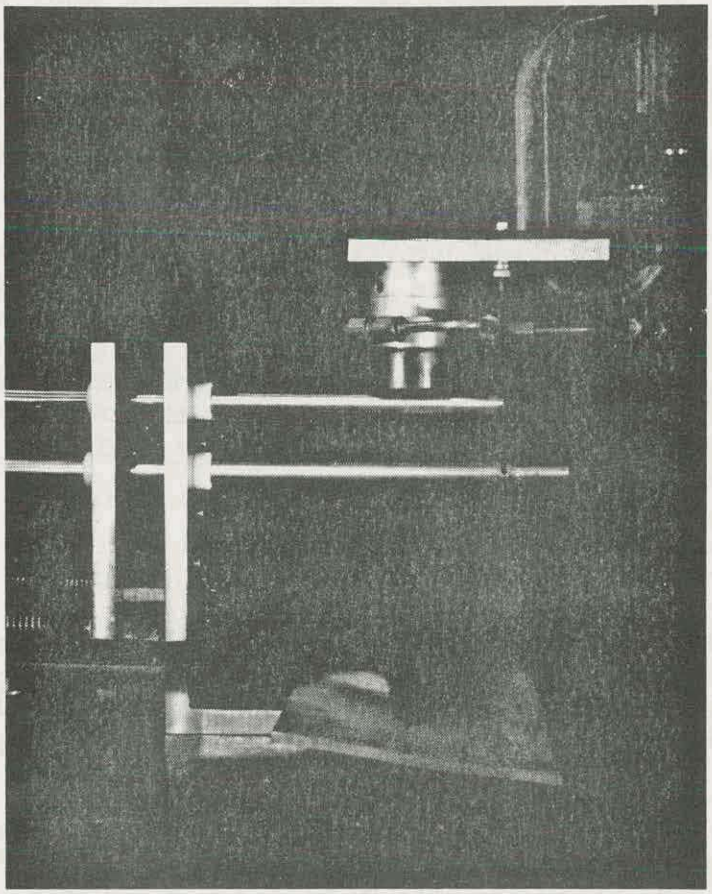
Based on prior experience, helium was chosen as the "cutting" gas for all the tests, and in general, 150 psi was used for all tests.

An f/18 reflecting optical system, consisting of water-cooled, polished mirrors was utilized for all tests. This system provided a sufficiently focused beam at any point in the array to enable the entire tube array to be cut without refocusing.

An Avco HPL® laser provided the 15-kilowatt, CW, CO_2 beam. This laser is a transverse flow device which incorporates an ionizer-sustainer design feature to initiate and maintain a uniform, controlled discharge in the optical cavity. A closed-loop power monitoring detector and controller provide capability to preprogram and maintain any power level required. The laser radiation occurs in the far infrared at a wavelength of 10.6 microns.

2.0 TEST PROCEDURE AND RESULTS

Initial experiments were first conducted on a single tube. Then, using two tubes, arranged one over the other, additional initial runs were made to evaluate the test setup and explore the parameter range which would be needed to achieve a satisfactory cut. Laser power was set at 15 kilowatts (maximum available) with cutting speeds in the range of 24 to 40 inches per minute (IPM). It was found that a single tube could be cut at 40 IPM using 100 psi helium gas jet.



TYPICAL FIXTURE SETUP

FIGURE B1-1

To achieve a full cut in one pass through two tubes positioned vertically, it was necessary to lower the speed to 24 IPM and increase the helium gas pressure to 150 psi. During the single-tube and two-tube arrangement cuts, the gas jet nozzle was located to the side of the upright tube holding fixture surfaces enabling it to be positioned 1/8 inch above the tube surface. This is shown in Figure B2-1.

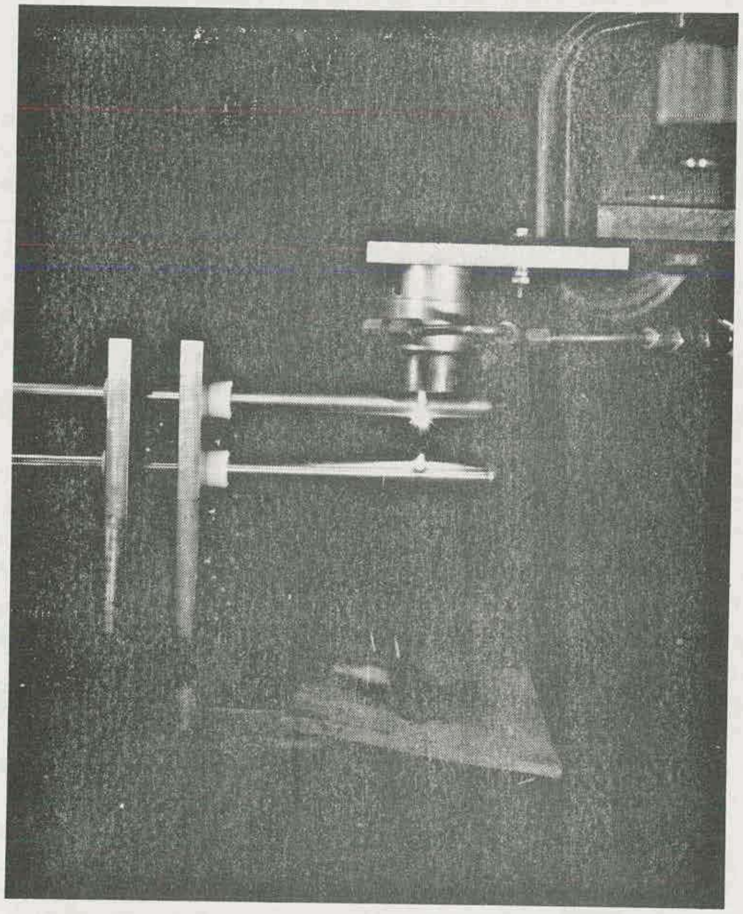
Subsequent testing investigated the parameters for cutting five tubes arranged vertically in the holding fixture. The gas jet nozzle remained positioned as for the initial tests, but to cut all five tubes in one pass, a transverse speed reduction to 8 IPM was necessary.

A full array of twenty tubes was setup in the tube holding fixture to observe the performance of the laser cutting process on a complete tube bundle. The gas jet nozzle location was retained at the same 1/8-inch position previously determined. The arrangement is shown in Figure B2-2. A single pass cut was made at 8 IPM and 15-kilowatt output power with the result that all but one tube was completely cut through. The uncut tube was located in the bottom row and was the last tube to be exposed to the beam. A second test was made, and the results were the same as the first test. The travel speed was reduced to 6 IPM in hopes of cutting all twenty tubes. However, this was not successful.

The ability of the laser to cut a twenty tube array in which the severed tubes remain in place during the cutting was also investigated. This more closely simulates the cutting of the fuel assembly top end fitting. The setup was modified by positioning the gas jet nozzle 1/8 inch above the tube holding fixture side plates (1/2 inch above the tube surface), which were spaced a distance of 3/8 inch apart. This spacing simulates the minimum distance anticipated between the PWR-type fuel pins and the top end fitting. The configuration is shown in Figure B2-3.

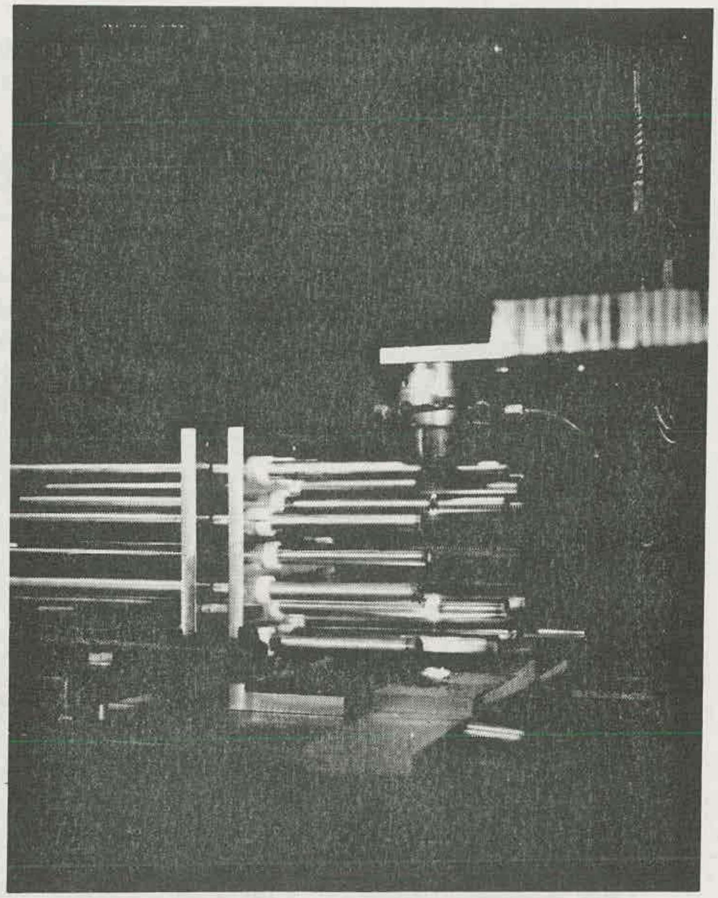
Single pass cuts were made at 6 and 5 IPM. At 6 IPM, five tubes were not cut through; and when using 5 IPM, four tubes were not cut. It was noted that the tubes which could not be cut were in the same physical location each time. The body of the gas jet nozzle was also found to be unexpectedly hot, indicating that some of the laser energy was being absorbed by the nozzle. Heat generated by the absorbed energy lead to thermal expansion, further obstruction of the beam periphery, and further reduction in the energy transmitted through the orifice nozzle to the tubes.

Based on the results achieved in the preceding run, it was decided to increase the spacing between the vertical plates of the fixture to 2.8 inches to permit the gas jet nozzle to be positioned just above the tube surface as in the earlier setups. A single pass was made at 5 IPM (requiring a beam "on" time of 1.4 minutes). After this pass, eight tubes remained uncut. The gas jet nozzle was permitted to cool to room temperature and a second pass was then made over the eight uncut tubes. The tubes were successfully severed (see Figure B2-4), demonstrating that an array of twenty tubes can be cut by the laser. The need for improved cooling in the gas jet nozzle was also apparent.



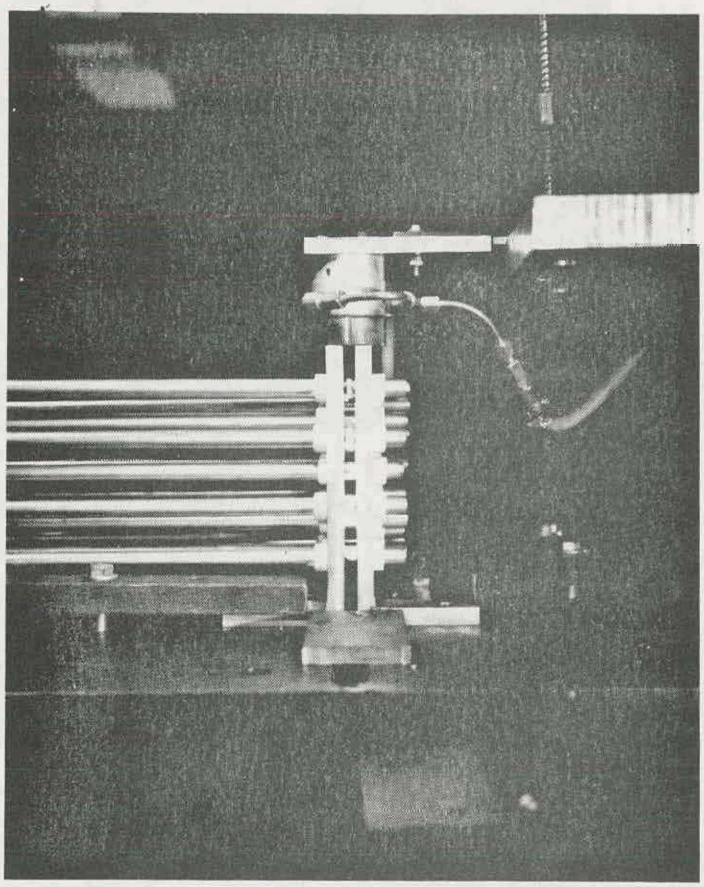
JET POSITIONED 1/8" ABOVE THE SURFACE

FIGURE B2-1



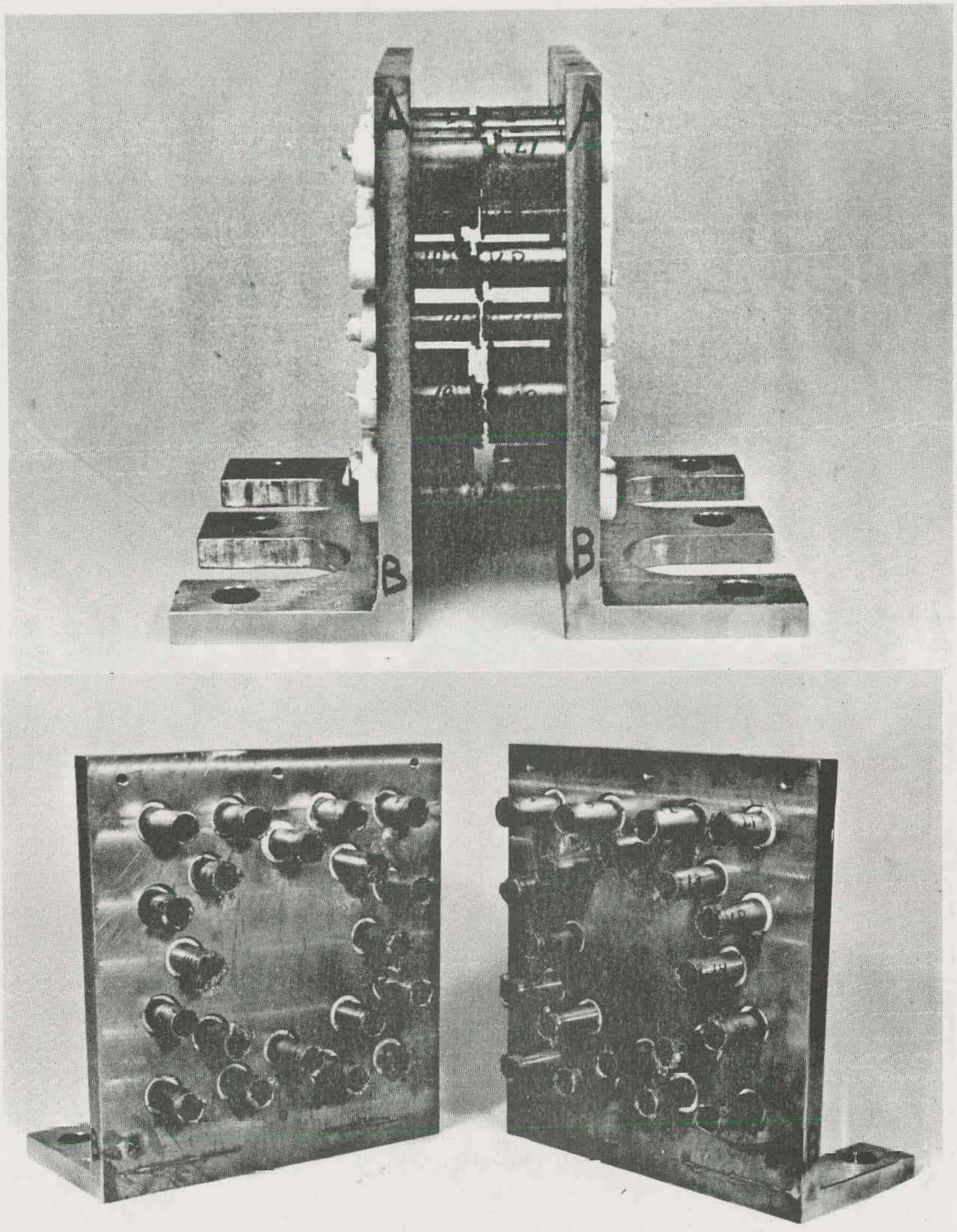
TWENTY TUBE CUTTING-GAS JET DISPLACED FROM FIXTURE

FIGURE B2-2



TWENTY TUBE CUTTING-GAS JET POSITIONED ABOVE FIXTURE

FIGURE B2-3



TUBES COMPLETELY SEVERED

FIGURE B2-4

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